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NORMAN WELLS AREA


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TERRAIN DISTURBANCE SUSCEPTIBILITY,

NORMAN WELLS AREA, MACKENZIE VALLEY

by

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for the
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1. SUMMARY

This geological study, undertaken in the Norman Wells area, N.W.T. since July 1971, is an investigation of the response of soil and rock materials to numerous natural and man-made disturbances under varying conditions. Preliminary terrain sensitivity maps of the study area have been produced in an attempt to designate the various zones of terrain units with similar properties and reaction to terrain disturbance.

The disturbances investigated were mainly forest fires, the removal of trees, and removal of surface vegetation and soil. Old and recent winter roads, seismic trails, and abandoned oil well sites were the primary subjects of detailed investigation, although the main emphasis was placed on a thorough study of the Canol Road and the Oscar Creek areas. Canol Road is the oldest major road and pipeline structure built in the N.W.T. and, with an abundance of access roads, seismic trails, camp areas, borrow pits and air strips, represents an ideal example of various types of man-induced terrain disturbances and resultant changes in different materials. Abandoned oil well sites and recently built networks of winter roads, seismic trails, and staging areas are representative of the most recent major terrain distrubance in the area.

The major factors affecting terrain performance are ground-ice and/or water content; engineering properties of soils especially grain size and index of plasticity; and surface morphology including local relief, degree, length, and orientation of the slopes. Other factors involved include type and extent of vegetation cover, season of the year, duration and intensity of the disturbing process, time elapsed since the disturbing force was applied, ground-water regime, etc.

Both natural and man-made terrain distrubances lead to an increased thickness of the active layer and degradation of permafrost. This increase can vary from almost negligible to very substantial and may result in extensive gullying, terrain subsidence, and ground-ice and thermokarst slumping. Ice-rich, highly plastic clays and silty clays on hillsides and sloping river banks are most prone to any type of disturbance which can result in severe erosion, rapid gullying, detachment slides and retrogressive flow slides.

2. INTRODUCTION

Permafrost is of vital importance in almost all phases of natural resource development programs in the Canadian Arctic and Subarctic regions. Adequate knowledge concerning the extent and behaviour of frozen ground must exist during the planning stages of activities such as exploration and mining, design and construction of pipelines, roads, railways, and foundations for large structures.

This study was carried out partly under the Geological Survey's continuing general program of geological and geomorphological information on northern terrain, and partly under the Environmental-Social Program,

Northern Pipelines, Task Force on Northern Oil Development, Government of Canada. This program was initiated after the first oil discovery in the Western Canadian Arctic in the winter of 1970 and its importance was further emphasized by the recent decision to construct the Mackenzie Highway from Fort Simpson to Tuktoyaktuk, N.W.T.

The study described in this report is a continuing investigation of the permafrost active layer and its behaviour, and of properties of various representative soil and rock types from comparable disturbed and undisturbed sites located around Norman Wells, N.W.T. The main objectives are to investigate the response of various soil and rock materials in different situations to several types of disturbance, both from natural and man-induced causes, and to develop a terrain sensitivity mapping system that will relate the performance or sensitivity of different terrain units to the activities of man, particularly those involved in the construction and operation of pipelines.

3. RESUMÉ OF CURRENT KNOWLEDGE

The major oil and gas discoveries of 1970 in the Arctic area produced increased interest in the North in general, and in the American and Canadian Arctic in particular. These discoveries and the recent decision to build the Mackenzie Highway through the N.W.T. have increased the need for more and better knowledge of the behaviour of permafrost terrain and the active layer as well as the effects of man's activities on the terrain and environment. This has subsequently led to an increased number of organizations and individuals involved in the engineering and scientific investigations pertinent to permafrost and terrain disturbance, and in turn, initiated a large number of relevant publications and reports.

The general knowledge and behaviour of permafrost and the history of permafrost investigation are well summarized by Terzaghi (1952), Leggett (1966), and Brown (1970). A number of studies concerning the effects of terrain disturbance have been published recently by various authors. Some deal mainly with general problems (USAGE, 1966; Brown, et al, 1969; Mackay, 1970; Hangen and Brown, 1971); others deal with specific problems such as forest fires (Hill, 1969; Heginbottom, 1971), pipeline construction (Lachenbruch, 1969; Leggett and MacFarlane, 1972; Isaacs and Code, 1972; Watson, et al, 1972; Slusarchuk, Watson, and Speer, 1972) and the effects of vehicle movement (Hok, 1969; Kevan, 1971). Other pertinent works concerning terrain disturbance and active layer behaviour may be found in the Proceedings of the Canadian Conference on Permafrost (Brown, 1969), Proceedings, Fire in the Northern Environment Symposium (Slaughter, Barney, and Hansen, 1971), and Proceedings, Canadian Northern Pipeline Research Conference (Legget, MacFarlane, 1972).

A series of reports is being produced under the Arctic Land Use Research Program of the Department of Indian Affairs and Northern Development. Several of these reports, especially those of Lambert (1970, 1972) and Kerfoot (1970, 1972) deal with the effects of terrain disturbance,

particularly removal of vegetation, on permafrost and the active layer. The current summary of reports on the relationship between permafrost, vegetation, wild life and landforms is given by Roberts-Pichette (1972). A list of environmental studies for the Mackenzie Valley Transportation Corridor has been compiled by Strang (1972).

4. STUDY AREA

The study area around Norman Wells, N.W.T. (Fig. 1) covers four adjoining 1:50,000 NTS map-areas (96 E/2, 96 E/3, 96 E/6 and 96 E/7). The entire area was covered in a general study of terrain disturbance, whereas detailed investigation of disturbed and undisturbed sites was undertaken in the vicinity of Norman Wells, along the Canol Road, and along the winter road on the east side of the Mackenzie River. A less intense study of terrain performance was carried out at several recently abandoned oil well sites near Oscar Lake and Three Day Lake; this study also included visits to several old and recent seismic trails, borrow pits, and staging areas.

Within the study area present and anticipated pipeline and highway activity is concentrated to the east of the Mackenzie River. In the vicinity of Norman Wells the highway and pipeline routes that are being considered traverse the gently rolling till plain between the river and Norman Range, while in the northwest corner of the area they follow the rock- and drift-covered lower slopes of the Norman Range.

4.1 Physiography and Geology

The Norman Wells area is part of the lower Mackenzie sedimentary basin and lies within the northeastern portion of the Cordilleran physiographic province. The general geology and geography of the Norman Wells area is described by Hume (1945) and Cook and Yorath (1972) with more detailed work on the Norman Wells Oil Field done previously by Hume (1922) and Stewart (1948). As part of the Canol Project a series of detailed reports on the Norman Wells area was produced by several authors (Canol Project Reports).

The study area is made up of a variety of rock types, chiefly Devonian. Shales, sandstones, carbonates and siltstones are of various ages; the oldest, Macdougal Formation of Cambrian age, is an interbedded series of shales, sandstones and limestones. The competent dolomites of the Ronning Group, forming the core of Norman Range, are of Silurian age. Of the following formations the majority of bedrock units are Devonian. The Bear Rock Formation dolomite, commonly brecciated, and the limestones of the Hume and Ramparts Formations provide a source of very good construction material and have been used for the construction of roads and the airport at Norman Wells. The Hare Indian and Imperial Formation shales, with thin beds of sandstone and siltstone, are moderately

competent rocks and fairly resistant to erosion. The Cretaceous and Tertiary shales are mainly soft, easily weathered rocks, prone to erosion and slumping; the Cretaceous sandstones are moderately competent rocks which locally weather into loose sand. The surficial geology is described by Hughes (1972) and mapped by Hughes (1970) and Fulton (1970).

The organic terrain is a peat, fen, and peat-fen complex of variable thickness, commonly occurring as a cover on the silt-clay and till plains. The silt-clay plains represent thick lake deposits and are often surfaced by sand or silty sand and/or organic cover. The till plains consist of clayey to silty till as a thin veneer on bedrock, particularly shale.

4.2 Location of Study Sites

Detailed investigations of terrain disturbance were undertaken at twelve sites centred about drill hole locations (Fig. 1). Seven of the sites are in the vicinity of the proposed pipeline and highway routes east of the Mackenzie River. Five of these (7A, 7B, 7C, 7D, MV) are on the till plain east of Norman Wells and two, (TL GL1) are on the silt-clay plain west of Norman Wells.

Five sites (GL 2U, CCU, SA, R1 and SD), on the west side of the Mackenzie River along Canol Road, are located within a variety of terrain units. Sites R1 and SD are on the till plain and sites GL 2U, CCU and SA lie within the silt-clay plain, beach sand ridge, and organic material respectively.

All three of the abandoned oil well sites visited are on till plain.

5. METHODS AND RESULTS

To achieve the objectives of this study, a three-fold approach was used. First an extensive examination and study of sites, disturbed in various ways either at a known time in the recent past or currently, was carried out to assess the effects of the disturbance on the different surficial geologic units and the active layer. The second approach included intensive field examination and mapping of the geological materials and their engineering properties within a sample area. The third approach involved laboratory testing of various soil and rock samples representing different geological and geomorphological units from both disturbed and undisturbed areas.

5.1. Field and Laboratory Methods

In studying previously disturbed sites, two main groups of factors were considered: 1) the type, intensity, and duration of activity, and 2) terrain engineering properties and conditions before and after disturbance. To assess these factors properly, their interaction and relationships must be considered. Since terrain details before disturbance are unknown, they are assumed to be identical to conditions of the undisturbed terrain contiguous to the area affected by the disturbance.

Three wide groups of activities, each of which can cause a different degree of terrain disturbances, were recognized in the Norman Wells area: oil and gas exploration, road and pipeline construction, and forest fires. Since the study of terrain disturbance resulting from forest fires was part of another study, detailed study of forest fire areas was excluded here and attention was concentrated primarily on the other two activities.

The study of oil and gas exploration activities included investigation of the abandoned oil well sites and examination and drilling on the seismic trails, access roads and staging areas. Part of this investigation involved detailed probing of active layer depth at three wild-cat well sites and drilling of seven holes along seismic trails. As seismic trails are so numerous and widespread in the study area, all drill holes were situated both on and off the trails close to the proposed pipeline and highway routes.

Intensive study and drilling were part of the investigation of Canol Road which is representative of construction activities. The depth of the five holes drilled varied from 10 to 60 m and both the chip and core samples were recovered for further testing in the soil mechanics laboratory to ascertain the engineering properties of each material. Tests included natural water content, Atterberg limits, sieve analysis, specific gravity, dry and bulk density, and pH. Ultrasonic wave velocities of frozen core samples were measured in the rock mechanics laboratory to determine the relationship between the compressional and shear wave velocities and ground-ice content as well as their possible application to field results of shallow seismic techniques.

All drill holes were instrumented with thermistor cables to provide a continuous record of air and ground temperatures at different depths.

5.2 Oil Well Sites

Oil and gas exploration and drilling has been widespread in the Norman Wells area since 1919. Recent activities consist mainly of seismic profiling, building of the staging areas and access roads, and drilling of exploration wells. Of the three recently abandoned oil well sites visited during the summer of 1972, two of them, Banff Aquitaine-Oscar

Creek No. 1 and No.2, were investigated in detail; the third, Aquitaine Mobile Dodo Canyon K-03, was occupied by the clean-up crew and hence only general observations were made.

The main part of the detailed investigation included measurements of thaw depth, notes on original and present conditions of the terrain and vegetation, notes on types and intensity of inflicted disturbance, and detailed study of the surficial geology.

All three oil well sites were generally rectangular, 150 by 200 m, with trees and bushes cleared and pushed to the sides by bulldozer. The moss cover was completely scraped away near the centre of the area with some patches left intact at the site edges. The well-head and immediately adjacent slush pit were located near the centre of the area while staging areas and the camp facilities were situated on the outside. Duration of site occupancy varied from three to six months, in winter and early spring. One or several seismic trails traverse or are immediately adjacent to the oil well site; the access road usually leads from the site to the nearest lake or stream.

The two Oscar Creek sites investigated were cleared during the winter of 1970 while the actual drilling activities took place in the spring of 1970. Both sites are on till plain with a thin till veneer overlying bedrock; the silty to clayey till is highly plastic with an average ice content around 25%. Several profiles were run across the well sites and depth of thaw was measured with a steel probe. In general, due to the concentration of drilling activities around the centre of the area, the depth of thaw was deepest close to the well head, became shallower towards the edges of the cleared area, and was very similar to the undisturbed area under the tree and brush remains.

At Oscar Creek No. 1 site three profiles were measured across the cleared area. Another profile, running parallel to the others, was measured in the undisturbed area off the drill site to enable comparison between the cleared and vegetated areas. The undisturbed area was covered with thin black spruce and a thick moss mat. The depth of thaw, shown in profile 3 (Fig. 2), varied between 15 and 20 cm and increased rapidly to 70 cm where the profile line crossed the seismic trail which was stripped of all vegetation cover.

Several profile lines were run across the access road leading from the well site to the nearby lake. Two sample profiles are presented in Figure 3. The access road was stripped of all trees and vegetation cover which, combined with the repetitive movement of various vehicles along the road, has resulted in rapid subsequent thawing. The deepest thaw coincided with the most frequently used centre part of the road where it reached 100-140 cm. Closer to the edges of the cleared area thaw depths decreased to 40-80 cm depending on the thickness of the remaining moss mat. The depth of thaw under slash piles at the edge varied between 20 and 30 cm which is similar to depths measured in undisturbed areas.

Similar conditions were encountered in the three thaw depth profiles measured at Oscar Creek No. 2 site as shown in Figure 4. Several adjacent seismic trails were examined and the measured profiles are shown in Figure 5. The depth of thaw under the disturbed area was much less than at the access road and since the area was not used by vehicles, is apparently due only to the removal of trees and vegetation cover.

5.3. Geological Survey Test-Hole Sites

In March and April 1972 in the Norman Wells area the Geological Survey cleared twelve drill sites and subsequently drilled bore holes. All sites were visited again during the summer of 1972 and the depth of thaw was measured twice in July and August. All adjacent seismic trails or winter roads were investigated at the same time.

Prior to drilling all sites had been cleared by bulldozing trees and brush to the sides, leaving the moss mat intact and covered with a thin layer of packed snow. At several sites subsequent drilling activities cut through the moss mat in places, but the resultant damage was very light. In general, terrain disturbance caused by the removal of vegetation cover and by drilling operations was almost negligible, except for the area in the immediate vicinity of the drill hole where disturbance was more noticeable. The measured depth of thaw was similar in both the recently disturbed and undistrubed areas.

Typical profiles of one GSC drill site are presentd in Figures 6 and 7. The GL 2U drill site, chosen as a representative example of all GSC drill sites, is situated off the Canol Road in fine silt-clay deposits with moderate ice content. Profiles 1 and 2 were run through both the drill site and the previously cleared right-of-way area adjacent to Canol Road. Measurements taken in July show that the average increase in the thaw depth was about 20 cm more in the cleared area compared with the undisturbed area; the increase under the right-of-way area was about 80 cm. Profile 4 was run through the area of actual drilling and showed a much greater increase in the depth of thaw than the other profiles. Profile 5, situated close to the edge of the disturbed area, shows a depth of thaw similar to profiles 3 and 6 which were run in the undisturbed area.

The August measurements show a general average seasonal increase of about 20 cm in the depth of thaw.

All investigations and measurements showed that careful removal of tree and vegetation cover using a bulldozer with the shoe-covered blades and combined with properly guided drilling activities caused very slight or no increase in the depth of thaw. With increased intensity of activities associated with drilling, severity of terrain disturbance increased and could lead to a very significant increase in thaw depth. In areas which had been previously cleared and extensively used, the depth of thaw

appeared to be much deeper and the vegetation regeneration process was much slower.

Two profiles were run across the adjacent seismic trail and the observed results are shown in Figure 8. The increase in depth of thaw due to the removal of the vegetation cover varied from 45 to 65 cm but was deepest under the centre of the trail.

One to three holes were drilled at each Geological Survey site to depths ranging from 10 to 60 m. Chip and core samples were collected from different depths, especially when a change in material occurred. All samples were described in the field and were again documented and analyzed in the soil mechanics laboratory to determine their engineering properties.

Stratigraphic and ice-type logs were made for each hole. Some representative logs are shown in Figures 9 to 12 and the accompanying legend shown in Figure 13.

5.4 Laboratory Analysis of Samples

All available laboratory results are summarized in Appendix A. The natural water content and grain size were obtained for all tested samples, while values of Atterberg limits, specific gravity, dry and bulk density and pH were measured only on representative samples.

About one hundred undisturbed core samples were recovered from seven drill holes located in a variety of surficial materials. Some twenty representative samples of differing materials were chosen and tested in the rock mechanics laboratory. The ultrasonic-pulse technique was used to measure compressional and shear wave velocities on samples with various ice contents; the equipment and operational procedure used have been described by Kurfurst and King (1972).

The measured results were evaluated and the ice/water content-ultrasonic wave velocity relationship was plotted. The frozen core samples were tested and measurements recorded at 30°F, 25°F and 20°F. At temperatures below 32°F when water in the sample starts to freeze, there is a sharp increase in both shear and compressional wave velocities with decreasing temperatures. The ultrasonic velocities of ice are much higher than those of unfrozen water, thus a sharp increase in the ultrasonic velocity is a good indication of increased ice content. A fairly close estimate of the ice content for various materials can be made from the range of measured velocities. Typical results are presented in Figures 14 to 16.

6. DISCUSSION

The study objectives of this report are to investigate and evaluate the response of various soil and rock materials under different conditions to various types of natural and man-caused disturbance and to develop a terrain sensitivity mapping system that can relate the performance of different terrain units to the activities of man. To achieve this objective it is necessary to thoroughly investigate all factors involved in terrain disturbance. Full understanding of the processes and activities and their interaction requires identification, evaluation, interrelation, and interpretation of all factors that affect terrain performance. This report deals only with identification and evaluation of the described factors; their interrelation and interpretation will be part of a further study.

Part of the "identification" phase included investigation and study of such activities as compaction of ground surface, destruction and removal of vegetation, and removal of surface vegetation mat and top soil. These activities and resulting disturbances are usually associated with gas and oil exploration; therefore, the results of investigation of oil well sites, adjacent seismic trails, and access roads as described in a previous section, combined with general observations, were the main sources of information. These activities are part of a number of processes that can affect terrain performance and cause varying intensities of terrain disturbance.

To prevent terrain disturbance an equilibrium must be maintained between the applied forces and terrain reactions. In general, the main applied forces are mechanical, thermal, hydraulic and gravitational or a combination of these operating within a time framework. When one or more forces are applied, the terrain response is immediate and may result in terrain disturbances varying from negligible to very severe. The ultimate degree of disturbance depends on terrain reaction which in turn depends on the type and intensity of the action applied, the ground-ice/water content, engineering properties of materials, and local morphology, especially the magnitude of slopes.

Disturbances caused by mechanical forces mainly depend on shear strength, grain size, cohesion, and friction of the surficial materials. Disturbances produced by thermal forces are dependent on air and ground temperature, ground-ice/water content, and the solid/fluid phase ratio. Disturbances by hydraulic forces are dependent on the ground-water regime and general drainage pattern; disturbances produced by gravitational forces are generally dependent on degree, aspect, and length of slope.

The application of one force can initiate or accelerate the application of other forces which acting in combination may result in greater impact and possibly more severe disturbance than that caused by the initial force.

Compaction of the ground surface and/or change in vegetation cover can alter the albedo, which can subsequently change the local drainage pattern and affect the thermal properties of the top soil layer. These changes can lead to increased heat flow downward from the surface during the summer, thereby increasing rate of thaw of the frozen soil. The resultant melting of excess ground ice can increase the depth of the active layer and accelerate the degradation of permafrost. Fine-grained, highly plastic soils with a high ground-ice content are most sensitive to changes in the temperature regime. Any significant thermal change on flat or gently sloping ground surfaces can result in permanent terrain subsidence and differential settlement. On steeper slopes, hillsides, and sloping river banks, extensive erosion, rapid gullying, various types of slope failures, and landslides may result. It appears that the ground-ice content is one of the major factors affecting sensitivity and performance of terrain under conditions of thermal disturbances. High ground-ice content in fine-grained soils of low plasticity can lead to adverse effects on the terrain performance.

The ultrasonic-pulse technique was used in the laboratory to measure compressional and shear wave velocities to effect a comparison with field results obtained from shallow seismic techniques. Measurements were made on a variety of samples, differing in surficial unit and ice content, at temperatures ranging between 30°F and 20°F (Figs. 14,15,16). The shallow seismic profiles were shot at the sampled drill sites at the time of drilling. Field and laboratory results are presented in Table 1:

Table 1

Drill site	Compressional wave velocities (ft/sec.)	
	Field data	Laboratory data
GL 2U	10,200	10,150 - 10,960
SA	9,000	8,240 - 9,160
GL 1	10,000 - 11,100	10,900 - 11,640
TL	8,100 - 9,250	8,100 - 11,890
MV	11,800 - 12,300	12,680 - 13,480
7B	7,200 - 10,700 8,300 - 11,900	6,640 - 10,210 8,110 - 11,890

Data from field and laboratory measurements are reasonably similar and show the compressional wave velocity ranges for samples of differing ice content in the various surficial units. The results obtained indicate that shallow seismic field techniques and laboratory ultrasonic methods can be used to determine ground-ice content and to assist, therefore, in predicting the reaction of various surficial materials to terrain disturbance.

6.1 Terrain Sensitivity Rating

Field observations and measurements were combined with laboratory results to compile a preliminary map of the area's terrain susceptibility to disturbance. Four 1:50,000 map-sheets of the Norman Wells area were produced and are shown in Appendix B.

Terrain disturbance susceptibility for the sample area was assigned to six map-units ranked from I to VI according to increasing terrain susceptibility to disturbance. Each unit contains materials of a common terrain morphology, ground-ice content, and engineering properties that respond to various types of disturbances in a similar manner.

Unit I consists of bedrock chiefly composed of competent sandstones, carbonates, siltstones and shales. Ground-ice content generally is nil or very low, except in shale where fractures may be filled with ice to depths of 30 to 45 m. Disturbance causes no changes involving permafrost degradation, except on steep slopes of frozen shale where minor rock slides and rotational slumps can occur. This unit is least susceptible to terrain disturbance.

Coarse and fine granular materials (gravels and sands) and silty sands and sandy silts on flat surfaces of less than 5° slope represent Unit II. These deposits usually form beaches, flood plains and river terraces, eskers, sand dunes, and plains bordering rivers. Generally they are poorly graded and have a low content of fines. Ground-ice content is low in coarse materials and increases with a higher content of fines. Minor ground-ice slumping, thermokarst subsidence, and local gullying can be caused by disturbance.

On slopes greater than 5° the silty sands and sandy silts described above are included in Unit III as are clayey and silty tills on flat surface of less than 5° slope. Tills commonly form ground moraine of low relief or a thin veneer on bedrock, particularly shale. They are fine-grained, moderately plastic (PI 17), less permeable materials with an average specific gravity of 2.65 and a natural water content of 28%. Moderate ice content with thin seams and locally thicker lenses of segregated ice makes these deposits moderately susceptible to thermokarst subsidence, gullying and ground-ice slumping when disturbed.

Tills on slopes greater than 5° as well as peat and fen complexes are rated as Unit IV. The organic peats and fens, generally overlying silt-clay and till deposits, are very porous with low specific gravity of 1.60 and extremely high natural water content at 200 to 1000%. This makes them highly compressible and very sensitive to changes in the temperature regime. Peat generally has moderate to high ground-ice content with up to 50% segregated ice. Fen is commonly unfrozen to a depth of 2 m with some segregated ice at greater depths. If disturbed, the peat and fen complex is highly susceptible to major terrain subsidence.

Unit V is composed of organic and inorganic clays and clayey silts on a flat surface of less than 5° slope. They are usually fine-grained, highly plastic materials with low permeability; ground-ice content ranges from moderate to high. Up to 10% of segregated ice occurs as thin seams in the upper layers with thicker tabular ice bodies at greater depths. Susceptibility to major thermokarst slumping and rapid gullying is very high.

Clays and clayey silts on slopes greater than 5° are ranked as Unit VI. They are extremely susceptible to major thermokarst slumping and rapid, deep gullying; large detachment slides and retrogressive flow slides are commonly caused by disturbance.

The detailed engineering properties of various materials from the Norman Wells area are tabulated in Appendix A.

It should be mentioned that apart from the three major factors described earlier, other parameters are involved in terrain disturbance and must be considered as well. Intensity and duration of the original disturbance, ground-water regime, precipitation, season of the year, terrain properties, and time elapsed since the disturbance are other important influences that can affect the sensitivity of the terrain in one way or another. More detailed study of all factors and their mutual effect is required before a more definite terrain sensitivity rating can be developed.

7. CONCLUSIONS

Several conclusions can be drawn on the basis of field observations and laboratory testing. Reaction of different soil types to any kind of natural or man-induced disturbance varies with their character, properties, surface morphology, and vegetation. It appears that the major factors controlling the reaction of the terrain and the effects of terrain disturbance are ground-ice and/or water content, engineering properties of the materials and surface morphology, especially slope and relief. Other factors, such as ground-water regime, precipitation, season of the year, intensity of the original disturbance, seem to have a lesser effect on the reaction of the terrain but under extreme conditions, can also cause an adverse reaction. Further detailed study of all factors involved and

their interrelationships is needed to increase our knowledge of the subject before more definitive conclusions can be drawn.

Generally, susceptibility to terrain disturbance of coherent bedrock and sand and gravel deposits is nil to very low and their performance is excellent. Till and organic sediments, depending on local conditions, are highly to moderately susceptible to terrain disturbance and their performance can be rated as good to fair. Clay and clayey silts are the materials most susceptible to terrain disturbance and their performance generally can be rated as poor.

8. RECOMMENDATIONS

Within the study area pipeline and highway are expected to be routed along the lowland between the Mackenzie River and the Norman Range. Here the till plain with low relief and discontinuous organic cover constitutes large areas with less difficult construction problems than other materials. Construction should be routed across this terrain where possible. Large organic areas as well as silt and clay plains, particularly those with thermokarst topography, are expected to present a variety of construction problems and should, therefore, be avoided where possible. Stream banks in Units IV to VI represent the most unstable conditions and are highly susceptible to terrain disturbance. Construction during winter, rather than summer, is expected to reduce the possibility of terrain disturbance.

To provide more insight on the actual behaviour of different terrain units during and after disturbance, it is suggested that part of the proposed pipeline be fully instrumented and all disturbance processes recorded.

It is also suggested that a further field test program be carried out to check and test sample maps of terrain susceptibility produced for different geographical and morphological areas around Norman Wells and the Mackenzie River delta. It is also felt that further use of ultrasonic and seismic methods for the determination of ice content should be made utilizing all available geophysical data collected by the oil companies and other agencies operating in the North.

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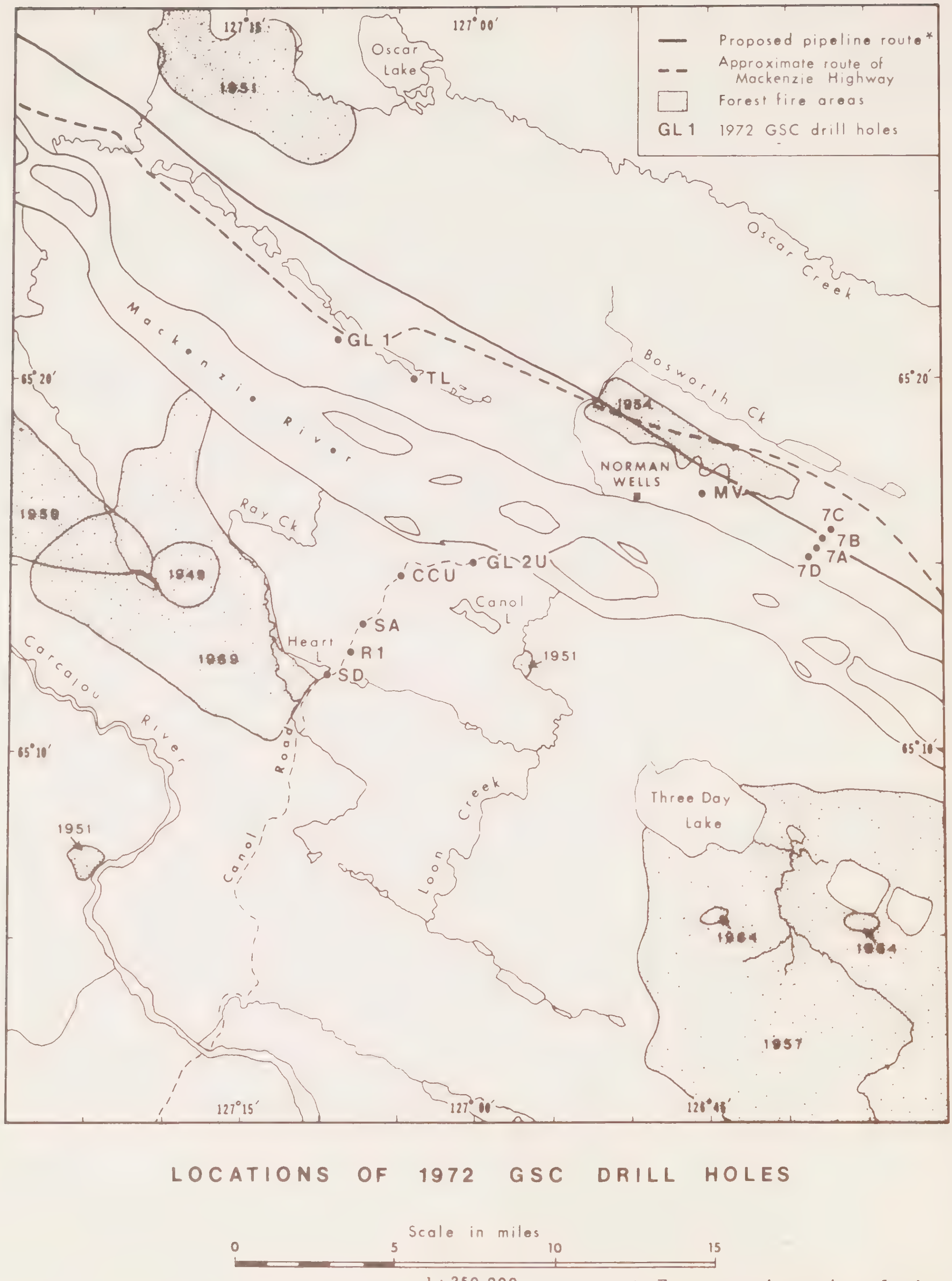


Figure 1 Locations of 1972 GSC drill holes

* For convenience in relating terrain to possible development, the approximate CAGSL route as of 1972 is shown.

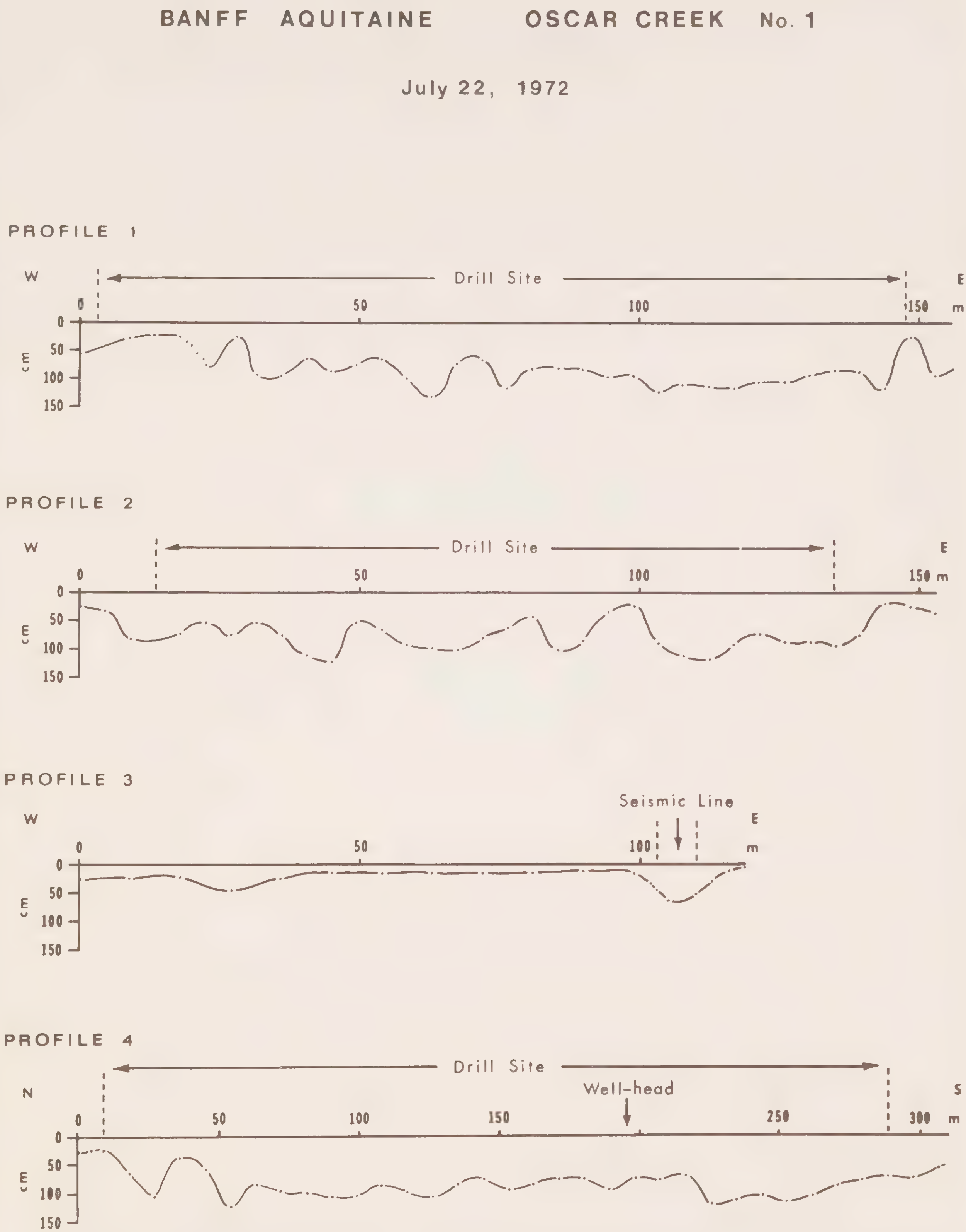


Figure 2 Profiles across oil well site - depth of thaw -
Oscar Creek No. 1

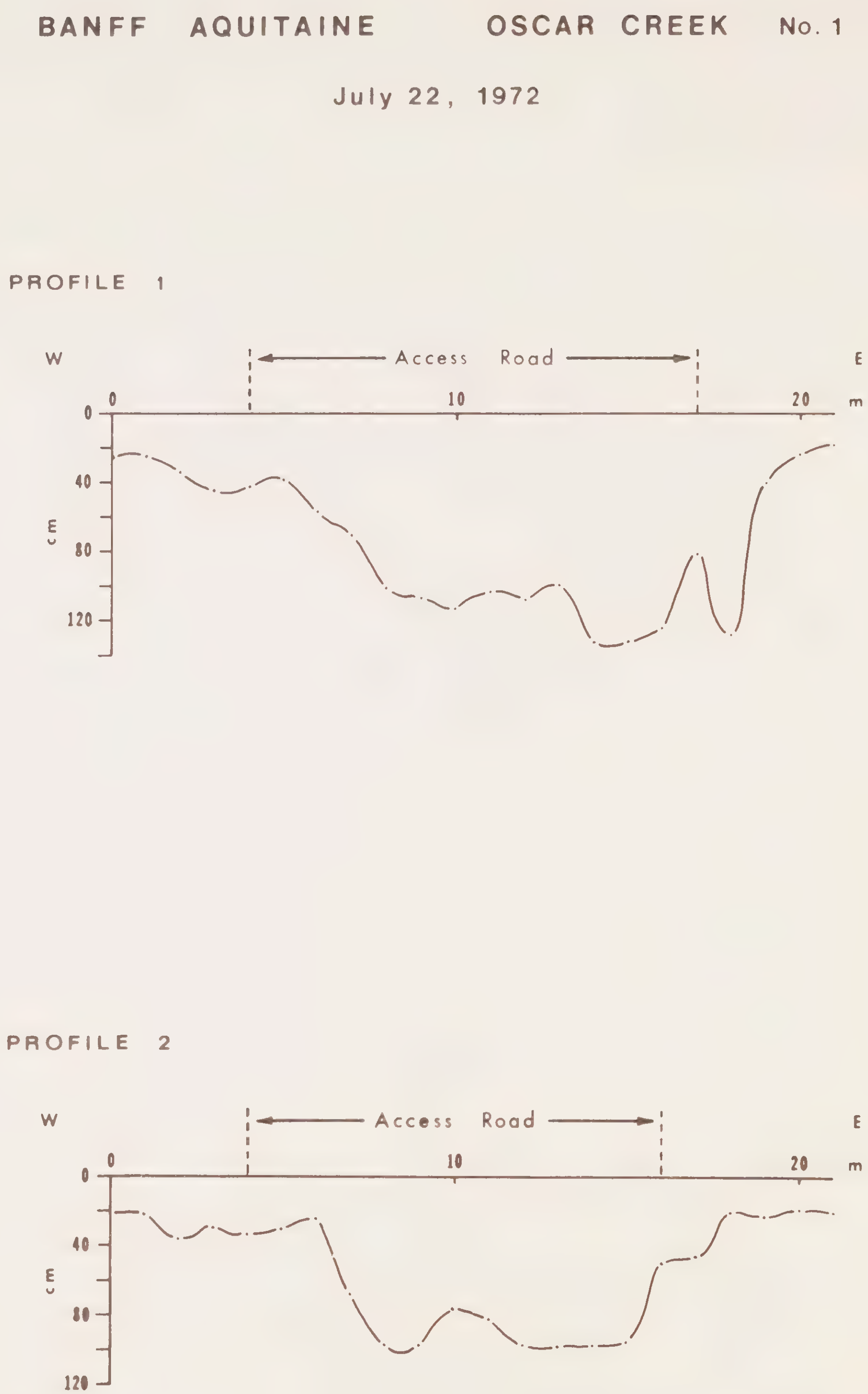


Figure 3 Profiles across access road - depth of thaw - Oscar Creek No. 1

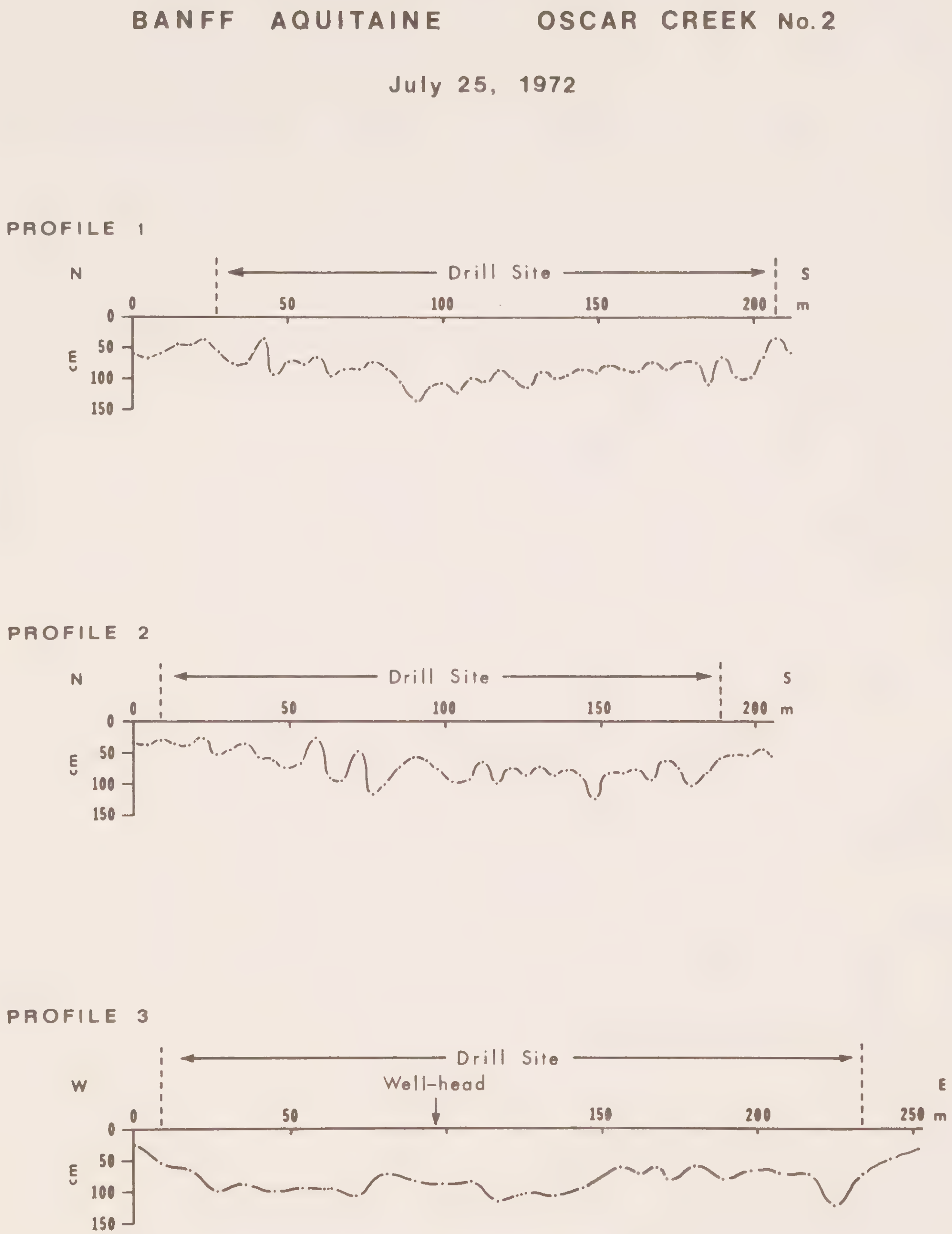
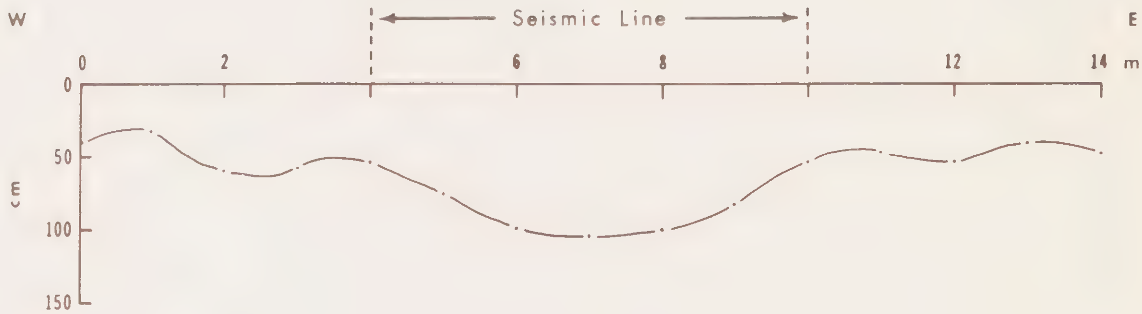


Figure 4 Profiles across oil well site - depth of thaw - Oscar Creek No. 2

BANFF AQUITAINE OSCAR CREEK No. 2

July 25, 1972

PROFILE 4



PROFILE 5

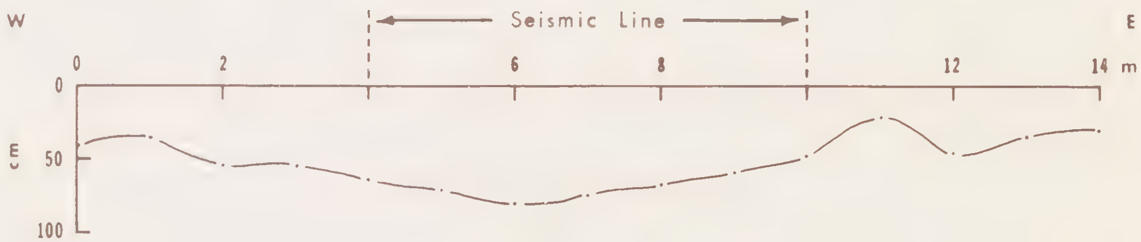


Figure 5 Profiles across seismic trail - depth of thaw - Oscar Creek No. 2

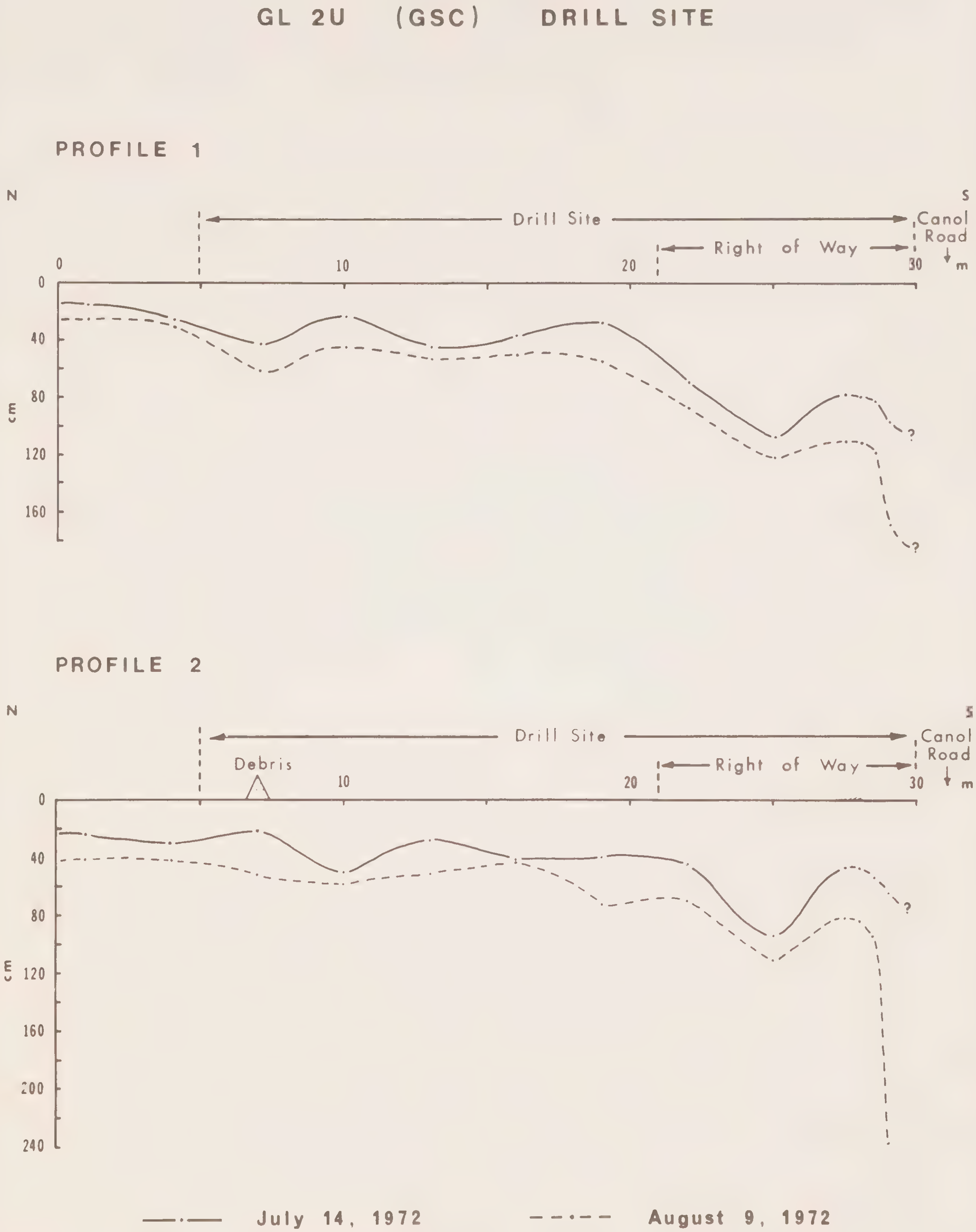


Figure 6 Profiles across drill site - depth of thaw - GL 2U drill site

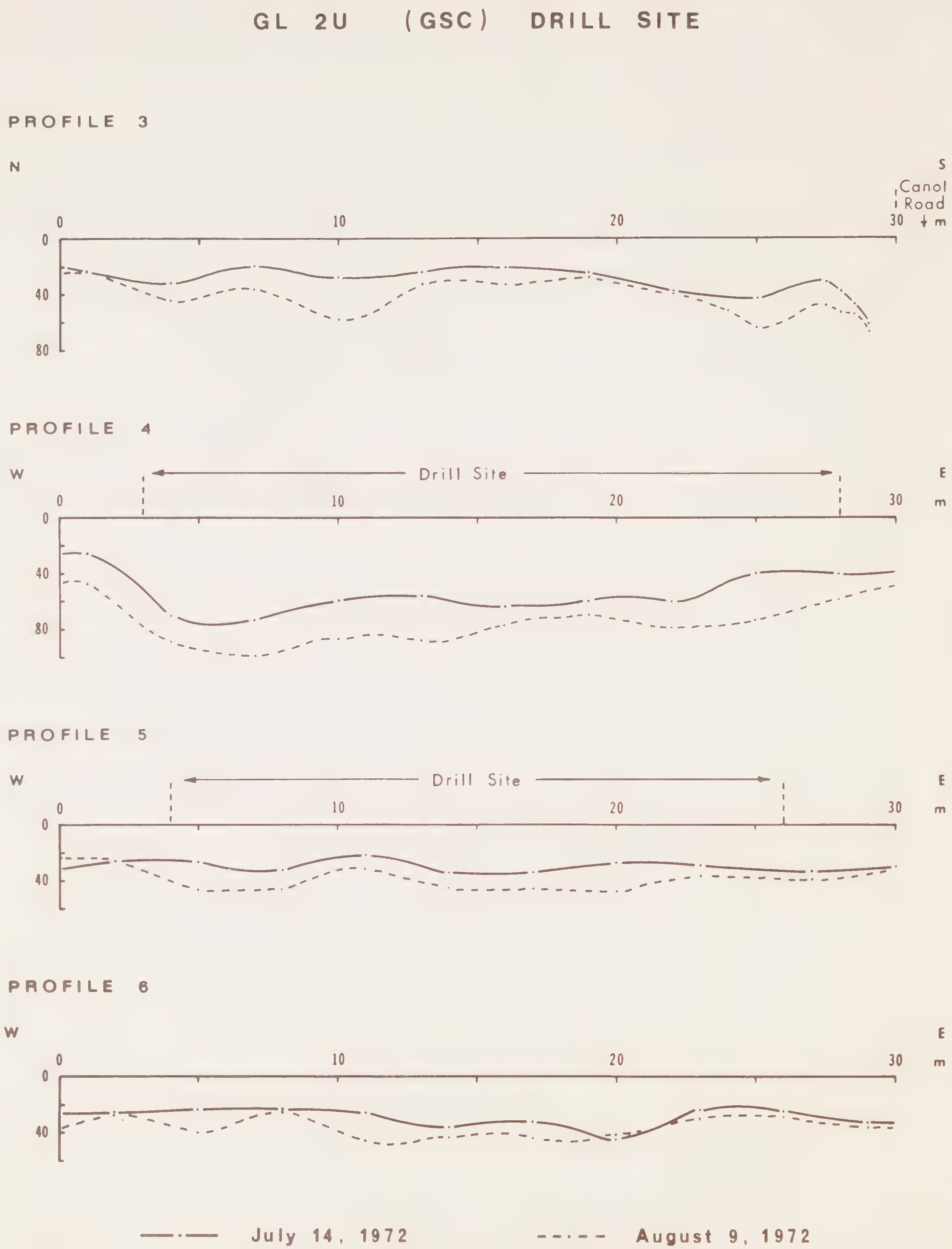


Figure 7 Profiles across drill site - depth of thaw - GL 2U drill site

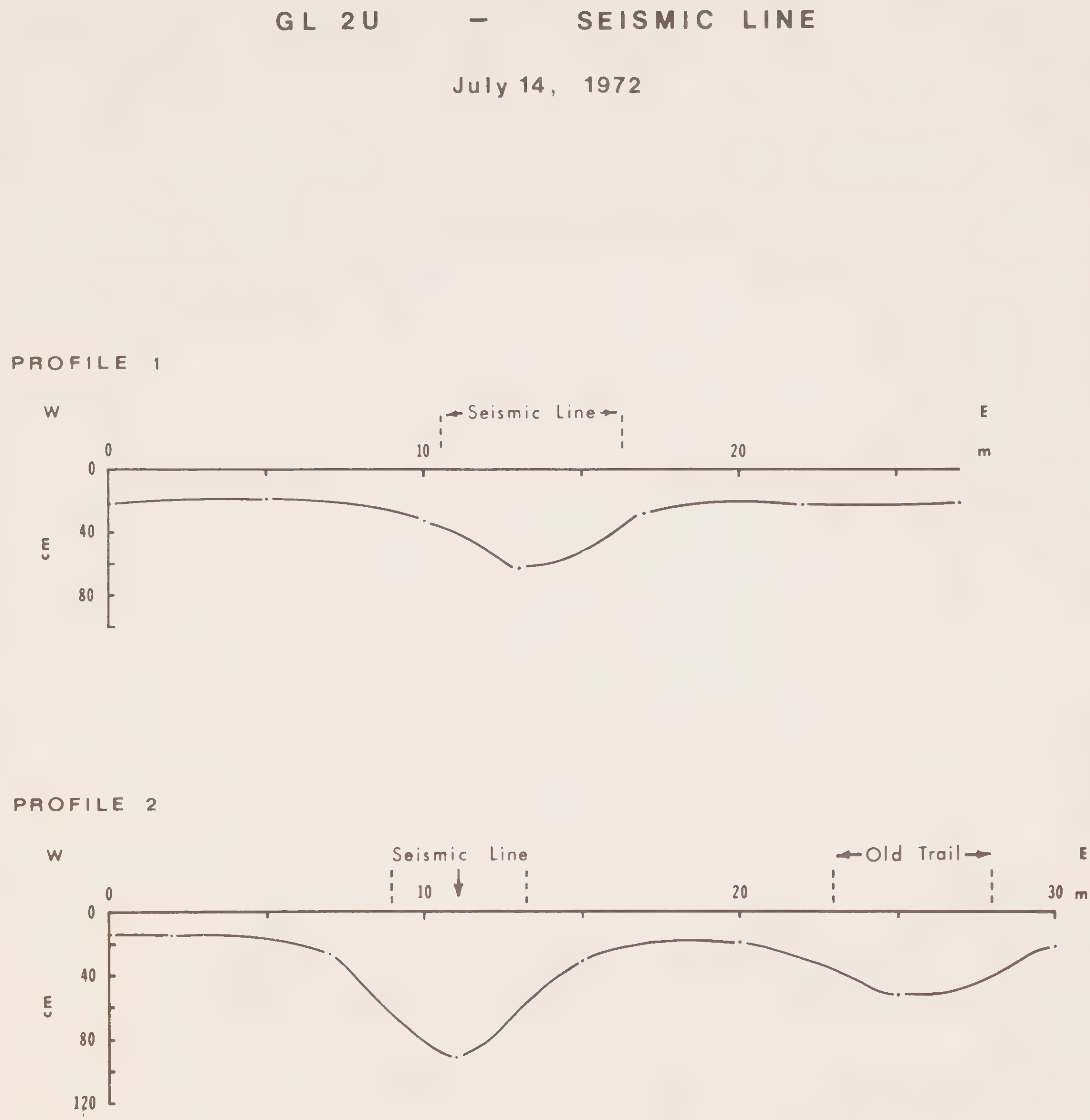


Figure 8 Profiles across seismic trail - depth of thaw - GL 2U drill site

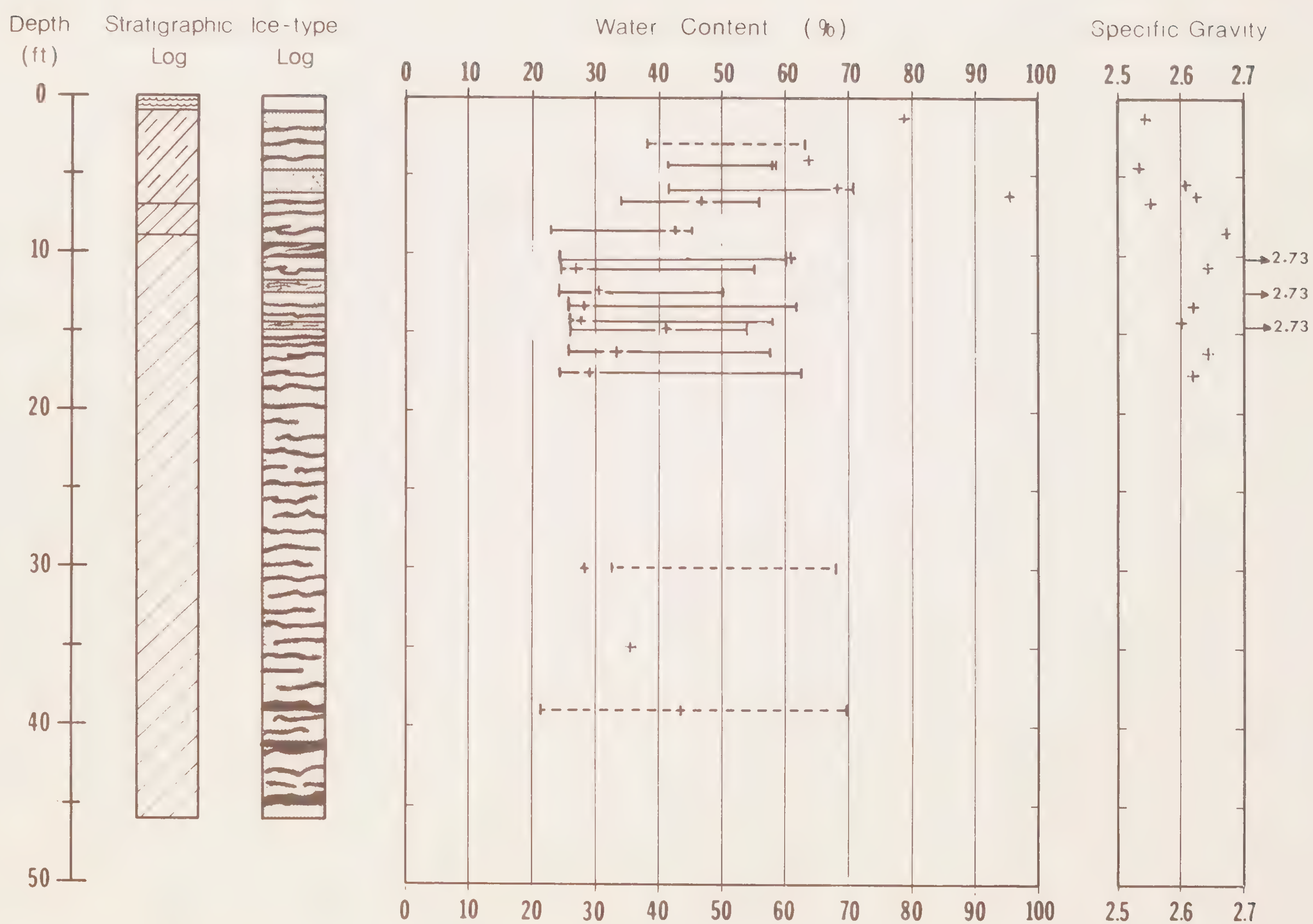


Figure 9

TL STRATIGRAPHIC AND PHYSICAL DATA

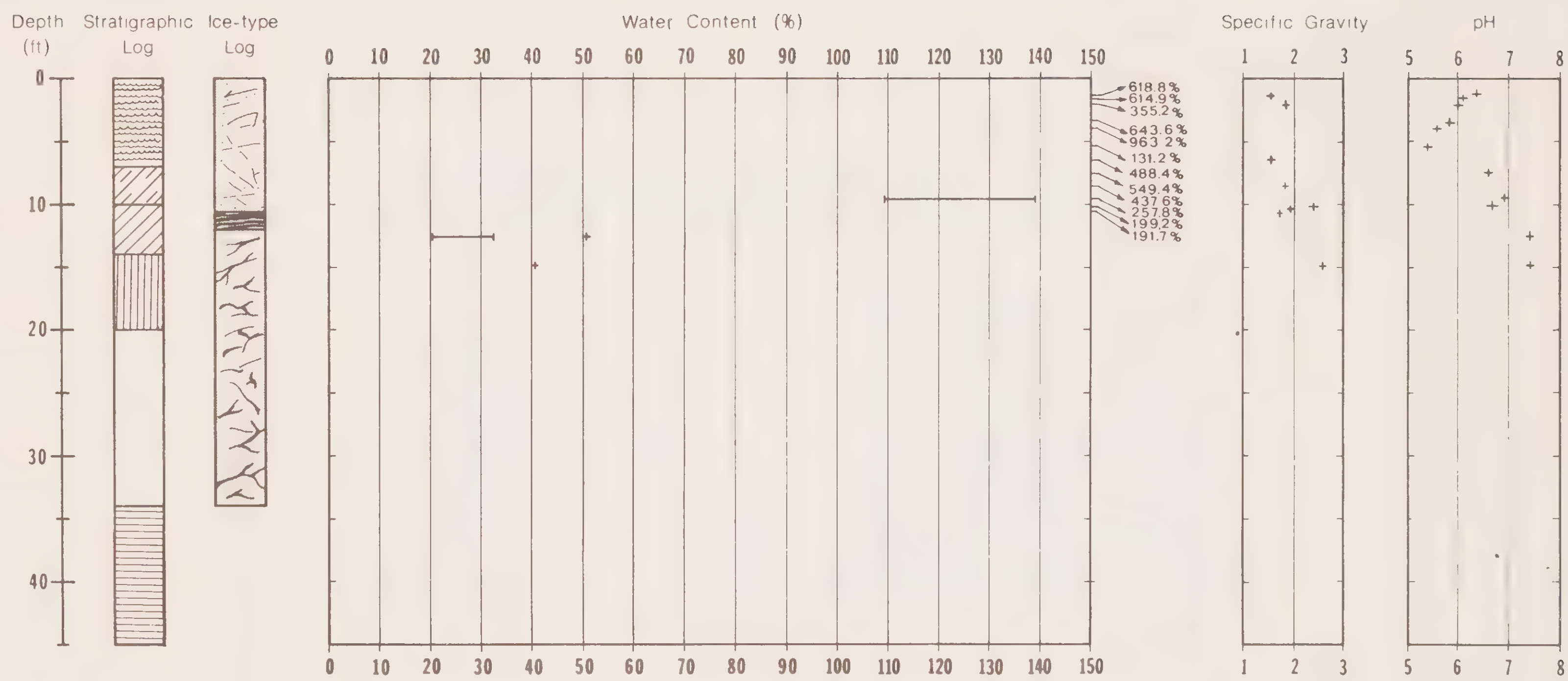


Figure 10

SA STRATIGRAPHIC AND PHYSICAL DATA

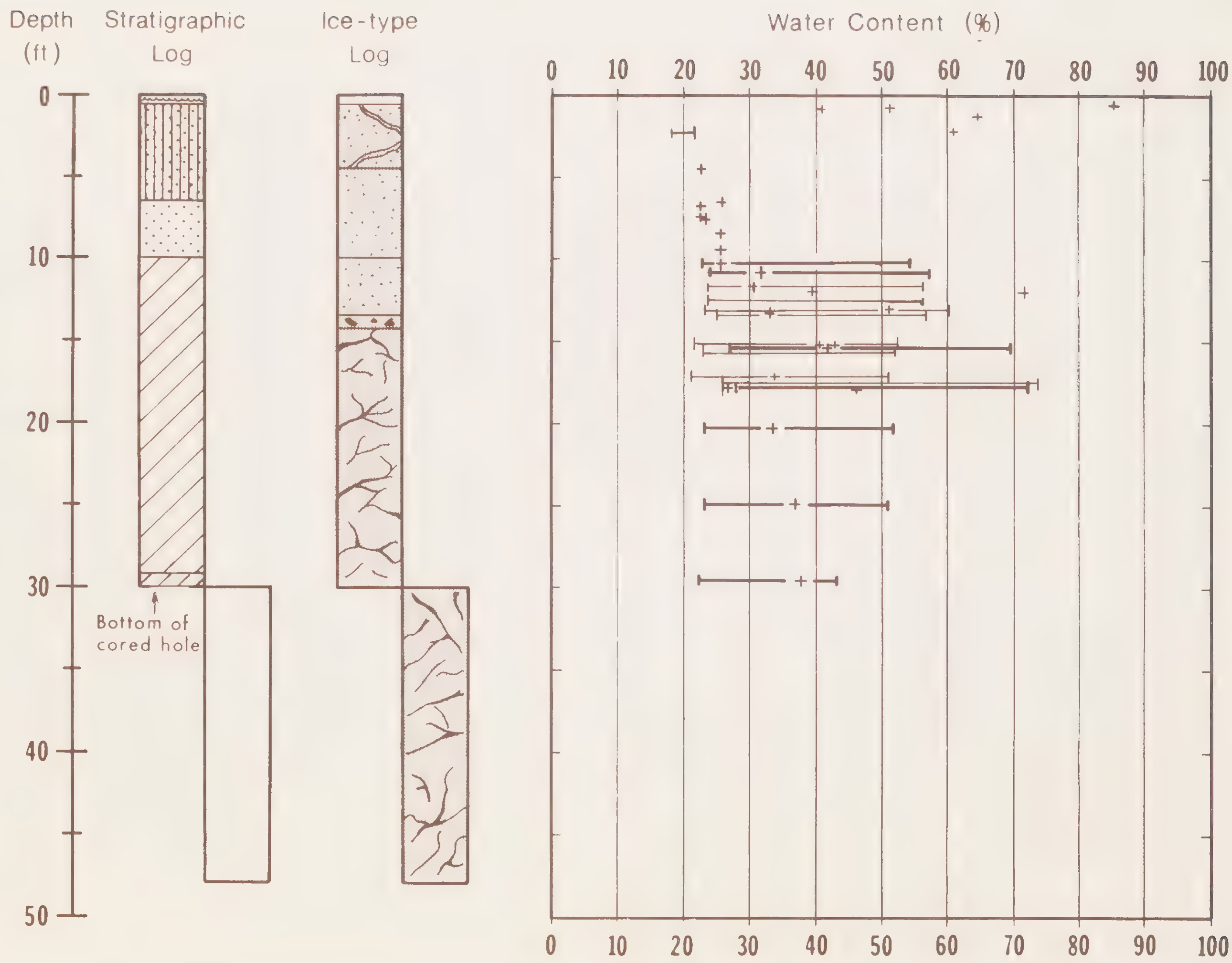


Figure 11

GL 1 STRATIGRAPHIC AND PHYSICAL DATA

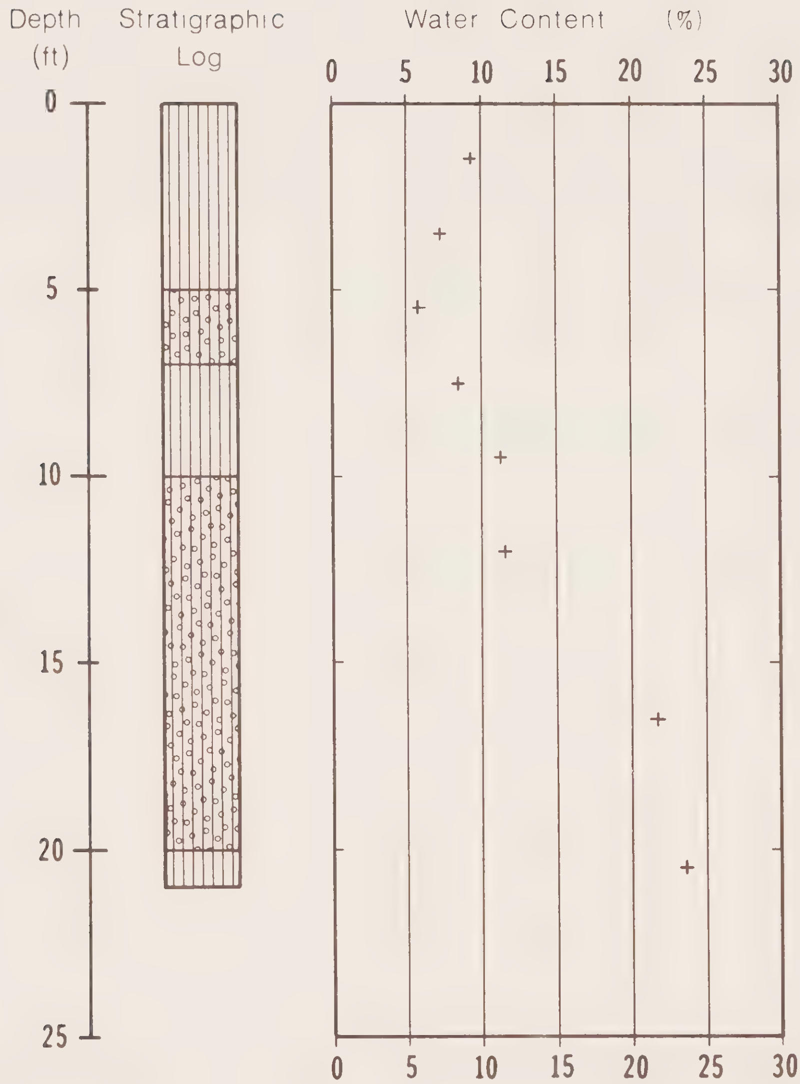


Figure 12

CCU STRATIGRAPHIC AND PHYSICAL DATA

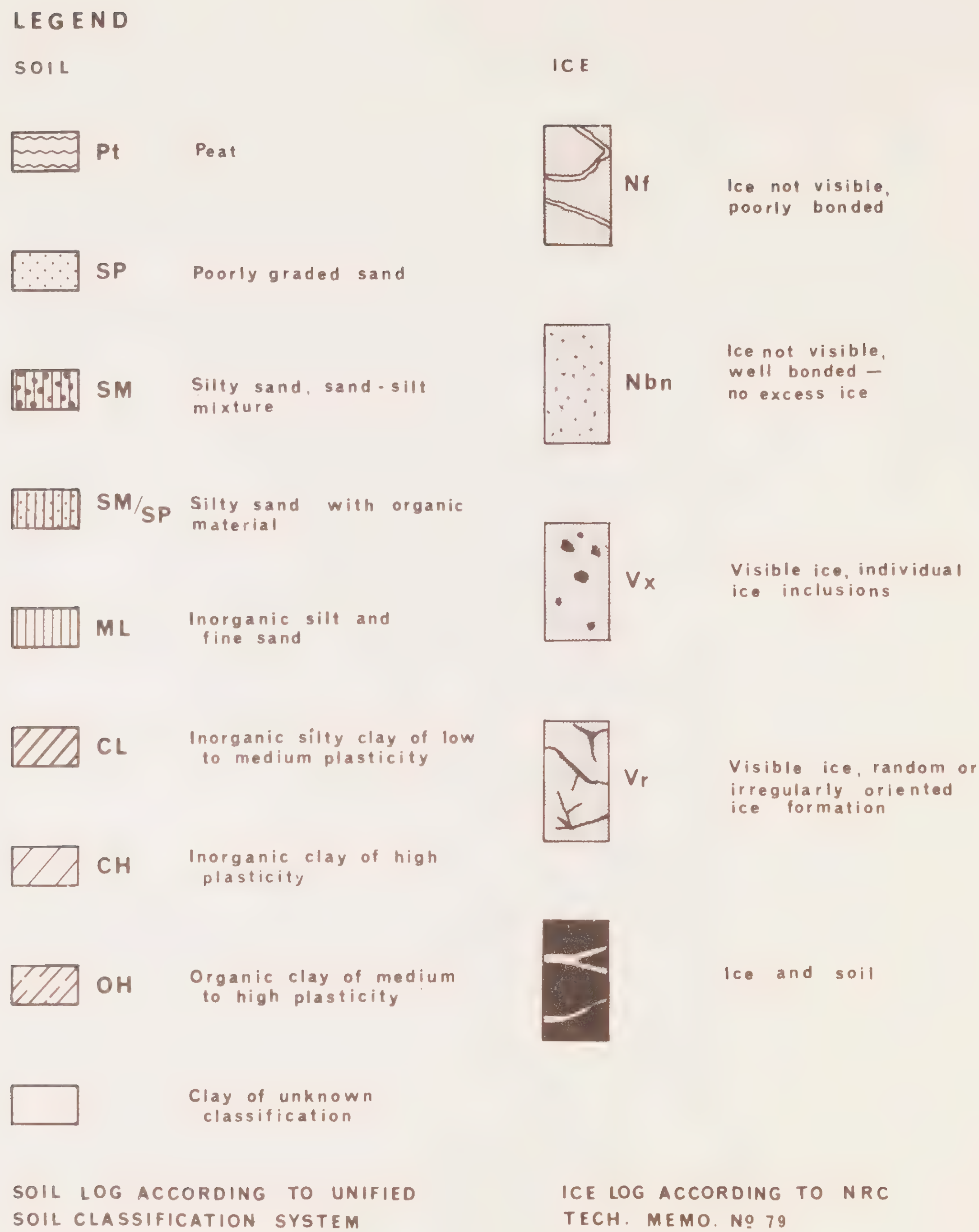
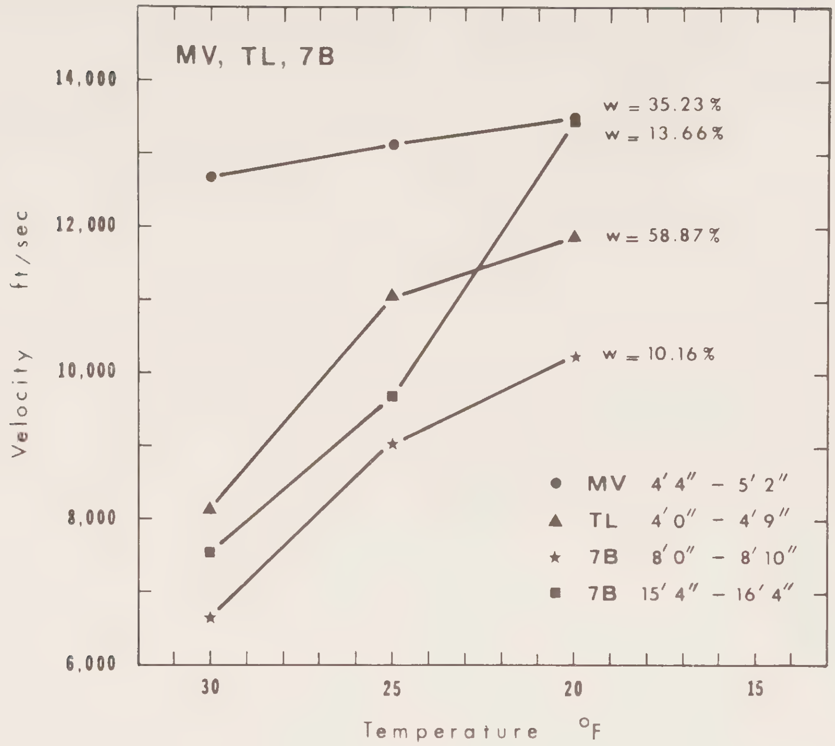


Figure 13 Legend for stratigraphic and ice-type logs



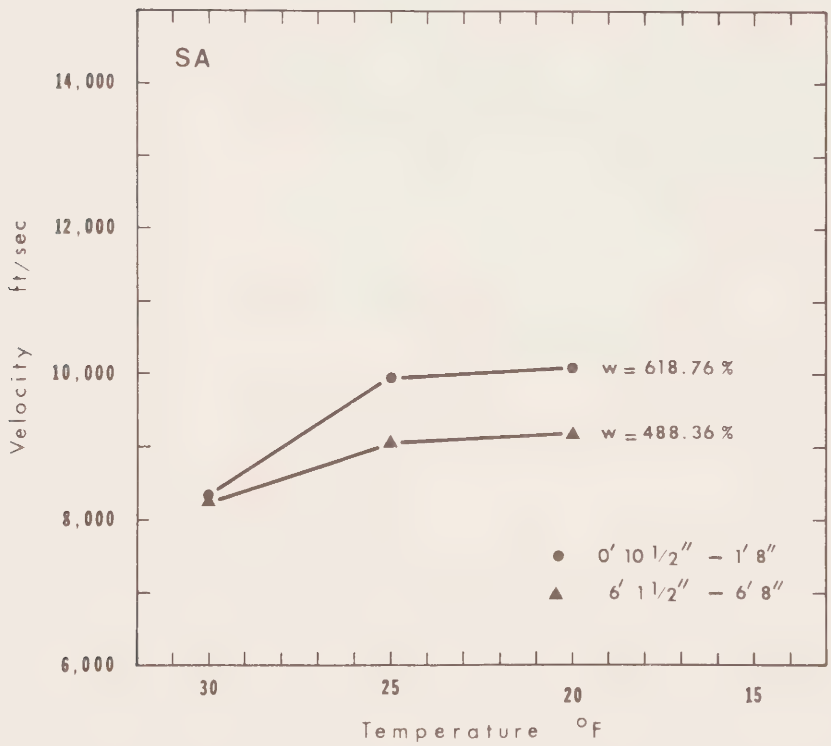


Figure 14

COMPRESSIONAL WAVE VELOCITIES vs. TEMPERATURE

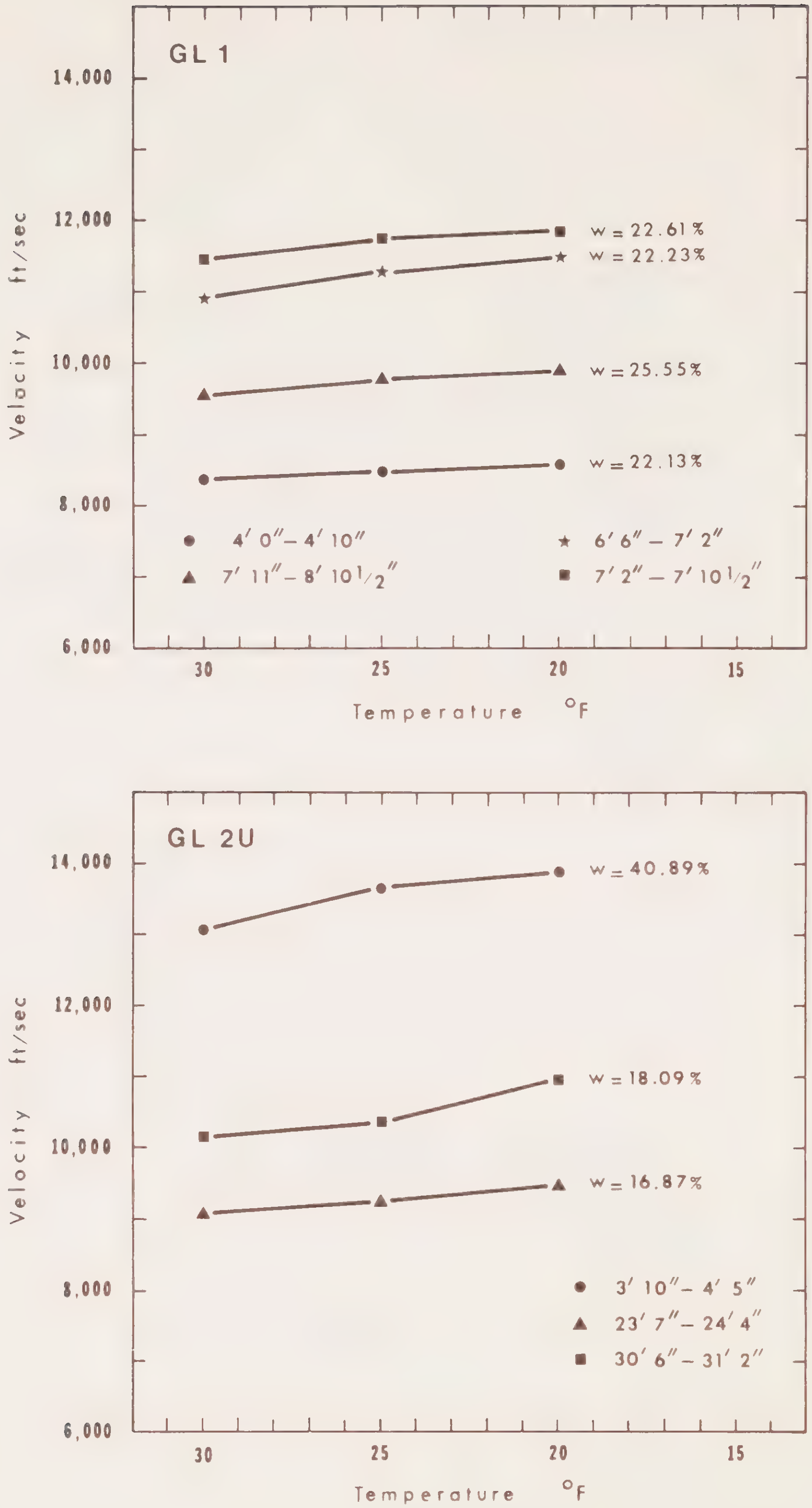


Figure 15

COMPRESSIONAL WAVE VELOCITIES vs. TEMPERATURE

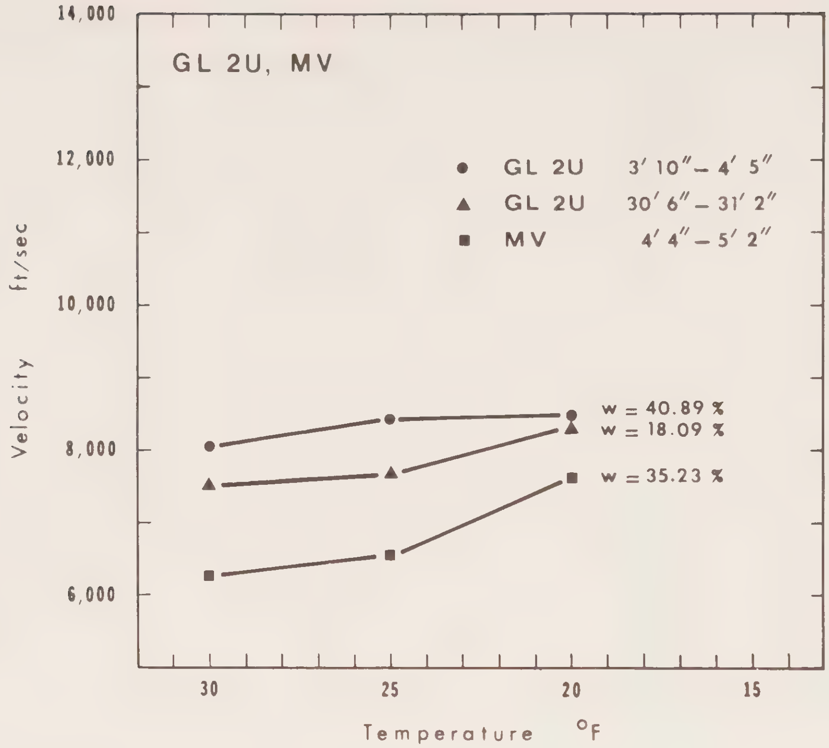


Figure 16
SHEAR WAVE VELOCITIES vs. TEMPERATURE

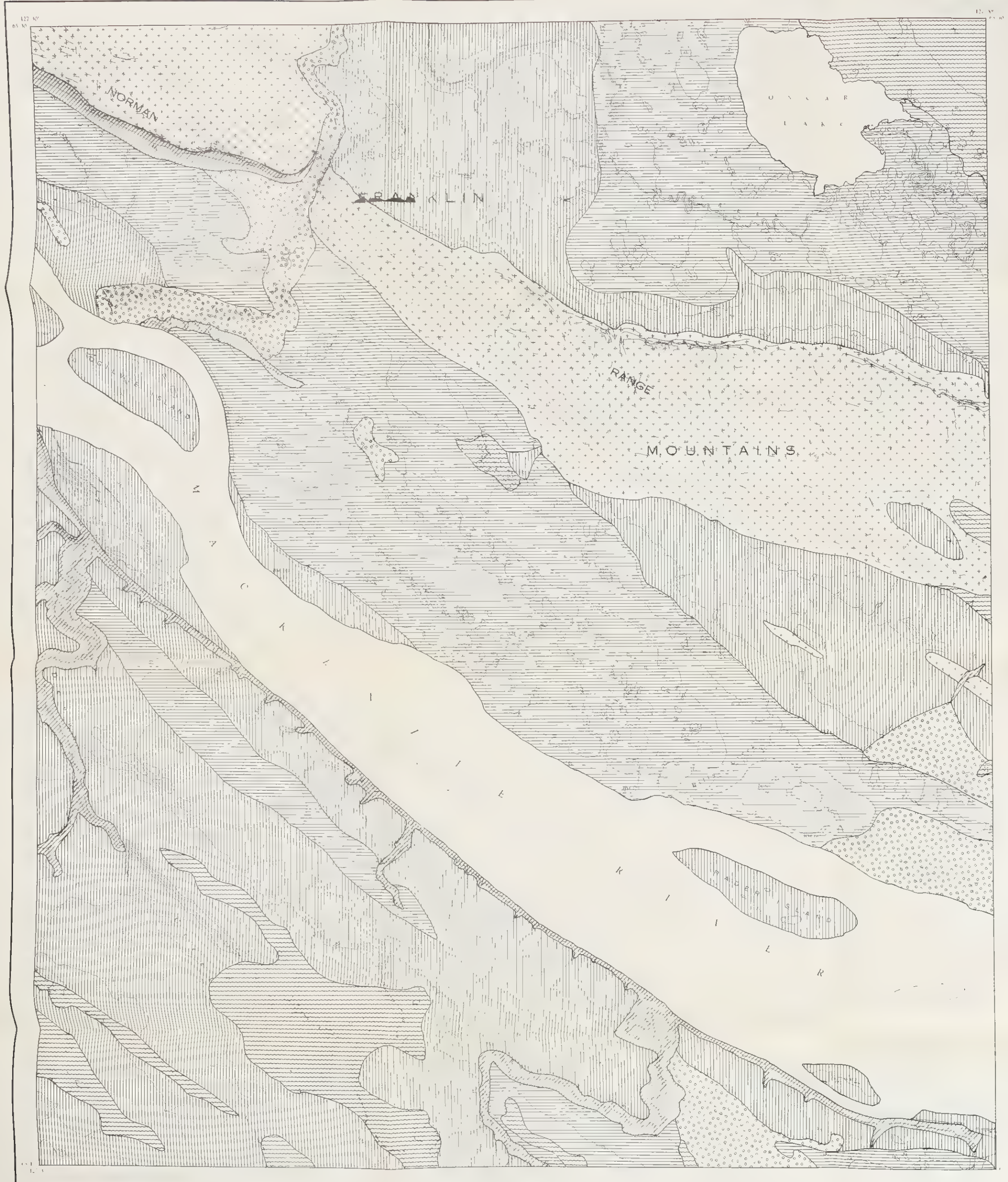
HOLE	DEPTH (feet)	NATURAL WATER CONTENT (%)	PLASTIC LIMIT	LIQUID LIMIT	PLASTICITY INDEX	SPECIFIC GRAVITY	pH
GL 2U	3'10"-4'5"	40.89				2.70	7.7
	23'7"-24'4"	16.87	24.8	44.8	20.0	2.66	7.8
	30'6"-31'2"	18.09	26.7	63.0	36.3	2.69	8.1
	37'4"-38'1"	8.57	28.1	62.6	34.5	2.67	8.1
TL	1'0"-1'4"	78.16				2.54	
	3'0"	50.50	38.7	63.1	24.4		
	4'0"	63.90					
	4'0"-4'9"	58.87	41.8	58.9	17.1	2.53	6.5
	6'6"-7'0"	46.60	34.5	55.8	21.3	2.55	
	8'4"-8'9"	42.25	22.8	44.9	22.1	2.67	
	10'8"-11'2"	26.30	24.4	55.0	30.6	2.64	
	12'10"-13'5"	28.74	25.2	61.1	35.9	2.62	
	14'0"-14'5"	27.79	26.0	58.2	32.2	2.60	
	15'10"-16'5"	33.55	25.7	57.4	31.7	2.64	
	17'5"-17'9"	29.02	24.3	62.4	38.1	2.62	
	30'0"	28.10	32.6	68.1	35.5		
	35'0"	35.80					
	39'0"	43.30	21.6	69.9	48.3		
GL 1	4'0"-4'10"	22.13				2.69	8.2
	6'0"-7'0"	25.93				2.66	
	6'6"-7'2"	22.23				2.69	8.2
	7'0"-7'11"	23.76				2.67	
	7'2"-7'10½"	22.61				2.67	8.2
	7'11"-8'10½"	25.55				2.66	8.2
	8'10"-9'11"	25.71				2.68	
	9'11"-10'7"	25.92				2.63	
	10'7"-11'1"	31.79				2.63	
	15'0"-15'4"	41.26	27.0	69.7	42.7	2.60	
	17'2½"-18'2"	26.92	28.8	71.9	43.1	2.69	8.0
	19'10"-20'6"	33.76	23.1	51.7	28.6		
	24'5"-25'4"	33.38	23.3	50.8	27.5	2.66	
	29'2"-30'0"	37.31	21.9	42.8	20.9	2.67	
MV	4'0"-4'4"	25.52	16.4	33.0	16.6	2.66	
	4'4"-5'2"	35.23	38.4	52.4	14.0	2.64	8.0
	6'0"-6'8"	56.48	39.2	60.6	21.4	2.37	
	7'6"-8'0"	26.62	21.9	35.5	13.6	2.73	8.2
	8'0"-8'6"	27.09	22.7	36.1	13.4	2.67	
	8'6"-9'3"	27.30	22.5	33.9	11.4	2.68	7.6
	9'3"-9'6"	26.03	22.4	30.1	7.7	2.68	
	10'1"-10'7"	29.09	21.9	38.1	16.2	2.69	
	12'6"-12'10"	25.49	21.5	30.9	9.4	2.66	
	13'10"-14'5"	28.40	24.0	29.5	5.5	2.65	8.2
	14'5"-15'4"	28.80	21.3	35.0	13.7	2.68	
	18'6"-19'0"	29.27	24.9	65.5	40.6	2.66	
	20'5"-20'10"	23.25	22.4	53.9	31.5	2.68	

HOLE	DEPTH (feet)	NATURAL WATER CONTENT (%)	PLASTIC LIMIT	LIQUID LIMIT	PLASTICITY INDEX	SPECIFIC GRAVITY	pH
SA	0'10½"-1'8"	614.90				1.55	
	1'0"-2'0"	618.76					6.1
	3'0"-3'6"	643.60					5.8
	4'0"	963.20					5.6
	5'0"-5'6"	431.20					5.4
	6'1½"-6'8"	488.36				1.60	
	7'0"-8'0"	549.40					6.6
	9'0"-10'0"	257.80	109.0	139.5	30.5		6.9
	11'0"-14'0"	50.40	20.3	32.3	12.0		7.4
	14'9"-15'0"	40.53				2.59	7.4
R 1	1'0"	13.20	16.4	33.0	16.6		
	2'0"-3'0"	21.60	27.5	41.0	13.5		
	4'0"	18.80	19.9	35.9	16.0		
	5'0"	13.30	15.1	23.6	8.5		
	6'0"-6'6"	16.10	19.5	37.0	17.5		
	8'0"-9'0"	14.60	19.0	41.1	22.1		
	11'0"-12'0"	16.00	18.2	41.3	23.1		
	13'0"-14'0"	14.40					
	21'0"-22'0"	11.20	18.2	41.6	23.4		
SD	4'0"-4'6"	649.0					
	7'0"-7'6"	28.40					
	10'6"-11'0"	21.60					
	11'11"-12'6"	14.34	15.4	20.5	5.1	2.70	7.7
	13'6"-14'0"	22.40					
	30'0"-30'6"	9.80					
	35'0"-35'6"	15.00					
CCU	1'0"-2'0"	9.30					
	3'0"-4'0"	7.40					
	5'0"-6'0"	5.80					
	7'0"-8'0"	8.10					
	9'0"-10'0"	11.30					
	10'0"-14'0"	11.20					
	16'0"-17'0"	21.80					
	20'0"-21'0"	23.60					
7 A	3'0"	13.66					
	7'0"-11'0"	7.81					
	15'0"-21'0"	4.11					
	34'0"-38'0"	8.65					
	50'0"-70'0"	5.26					
	80'0"-85'0"	3.67					

HOLE	DEPTH (feet)	NATURAL WATER CONTENT (%)	PLASTIC LIMIT	LIQUID LIMIT	PLASTICITY INDEX	SPECIFIC GRAVITY	pH
7 B	5'2"-5'10"	36.28				2.62	
	8'0"-8'10"	10.16	19.3	40.2	20.9	2.70	8.2
	8'6"-9'0"	33.95				2.63	
	10'0"-11'3"	15.53				2.69	
	11'10"-12'4"	13.43				2.70	
	13'5"-14'4"	8.21				2.70	
	15'4"-16'4"	13.66	19.8	29.6	9.8	2.71	8.1
	16'4"-17'4"	15.06				2.69	
	22'0"	15.26					
	40'0"-41'0"	11.01					
	45'0"-46'0"	7.89					
	50'0"-51'0"	8.07					
7 C	2'0"-6'0"	10.71					
	8'0"-13'0"	12.34					
	14'0"-17'0"	4.46					
	19'0"-	5.35					
7 D	2'0"	71.10					
	4'0"	88.20					
	8'0"	13.20					
	10'0"	10.50					
	12'0"	9.20					
	14'0"	9.90					
	42'0"	9.60					
	61'0"	7.40					
	80'0"	6.60					
	95'0"	6.50					

GEOLOGICAL SURVEY OF CANADA
DEPARTMENT OF ENERGY MINES AND RESOURCES

NATIONAL TOPOGRAPHIC SYSTEM | 1:50,000 | FIRST EDITION | SHEET 96 E/6



OSCAR LAKE
DISTRICT OF MACKENZIE
NORTHWEST TERRITORIES

SCALE 1:50,000
1.25 inches to 1 mile approximately

CONTOUR INTERVAL 50 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927 (1953)
Transverse Mercator Proj.

REFERENCE

REFERENCE

LEGEND

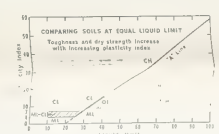
INCREASING TERRAIN SUSCEPTIBILITY TO DISTURBANCE

Susceptibility rank	Map Unit	Soil type symbol	General description	Comments
I			Bedrock – shales, sandstones, carbonates and siltstones. Very low ice content except in shale where fractures are filled with ice to depth of 100–150 ft.	Competent carbonates and sandstones can be used as source of granular material. Rock falls and slides occur on steep slopes, rotational slumps common on high cliffs of shale. No changes caused by disturbance except on steep slopes of frozen shale.
II		GP	Gravel – medium to coarse, poorly graded, high permeability. Low ice content in coarse materials; locally ice lenses in finer sediments. Ground ice generally absent in beach sediments.	Good source of granular material. Locally minor ground ice slumping and thermokarst subsidence can be caused by disturbance.
		SP	Sand – fine to medium, poorly graded, moderate to high permeability. Low to moderate ice content, seams of segregated ice.	Suitable as source of granular material. Minor ground ice slumping and thermokarst subsidence can be caused by disturbance.
		SM	Silty sand, sandy silt-fine, poorly graded, low permeability, on slopes <5°. Moderate to high ice content, locally with thin lenses of segregated ice. Discontinuous organic cover up to 10 ft.	Poor source of borrow material, can be improved by artificial drying. Minor ground ice slumping, gullying, and thermokarst subsidence can be caused by disturbance.
III		CL	Clayey to silty till – fine, low to medium plasticity, low permeability, on slopes <5°. Moderate ice content with thin seams and locally thicker lenses of segregated ice. Discontinuous organic cover up to 10 ft.	Suitable as borrow material (fill) only where ice content is low. Low to moderate susceptibility to thermokarst subsidence, gullying and ground ice slumping due to disturbance.
		SM, ML	Silty sand, sandy silt – fine, poorly graded, low permeability, on slopes >5°. Moderate to high ice content, locally with thin lenses of segregated ice. Locally overlain by patches of organic cover.	Poor source of borrow material, can be improved by artificial drying. Moderate susceptibility to thermokarst subsidence; gullying and ground ice slumping due to disturbance.
IV		Pt	Peat and fen complex – porous, high compressibility, extremely high moisture content. Peat – moderate to high ice content, up to 50% of segregated ice, locally unfrozen from 1 to 3 ft. Fen – commonly unfrozen to depth of 6 ft., locally some segregated ice at greater depths.	Unfavorable for construction purposes. High susceptibility to terrain subsidence due to disturbance.
		CL	Clayey to silty till – fine, low to medium plasticity, low permeability, on slopes >5°. Moderate ice content with thin seams and locally thicker lenses of segregated ice. Irregular patches of organic cover.	Suitable as borrow material (fill) only where ice content is low. Moderate to high susceptibility to thermokarst subsidence, gullying and ground ice slumping due to disturbance; locally superficial mudflows and flow slides.
V		OH, CH	Organic and inorganic clay, clayey silt – very fine, low permeability, high plasticity, on slopes <5°. Moderate to high ice content. Up to 10% of segregated ice as thin seams in upper layers, tabular ice bodies at greater depths. Discontinuous organic cover up to 10 ft.	Very poor source of fill material. High susceptibility to major thermokarst slumping and rapid gullying due to disturbance.
VI		OH, CH	Organic and inorganic clay, clayey silt – very fine, low permeability, high plasticity, on slopes >5°. Moderate to high ice content. Up to 10% of segregated ice as thin seams in upper layers, tabular ice bodies at greater depths. Irregular patches of organic cover.	Very poor source of fill material. High susceptibility to major thermokarst slumping and rapid gullying due to disturbance; large detachment slides and retrogressive flow slides common.

Note: Soil symbols according to Unified Soil Classification System.

UNIFIED SOIL CLASSIFICATION

FIELD IDENTIFICATION PROCEDURES				GROUP SYMBOLS	TYPICAL NAMES	LABORATORY CLASSIFICATION CRITERIA		
COARSE GRAINED SOILS More than half of material is larger than No. 200 sieve size	GRAVELS	More than half of coarse fraction is larger than No. 4 sieve size	CLEAN GRAVELS	GW	Well graded gravels, gravel-sand mixtures; little or no fines	Depending on percentage of fines coarse grained soils are classified as follows: Less than 5% GW, GP, SW, SP; More than 12% GM, GC, SM, SC; 5% to 12% Borderline cases requiring use of dual symbols		
				GP	Poorly graded gravels, gravel-sand mixtures; little or no fines			
			GRAVELS WITH FINES	GM	Silty gravels, poorly graded gravel-sand-silt mixtures		Atterberg limits below "A" line, or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
				GC	Clayey gravels, poorly graded gravel-sand-clay mixtures		Atterberg limits above "A" line, with PI greater than 7	
	SANDS	More than half of coarse fraction is smaller than No. 4 sieve size	CLEAN SANDS	SW	Well graded sands, gravelly sands; little or no fines			
				SP	Poorly graded sands, gravelly sands; little or no fines			
			SANDS WITH FINES	SM	Silty sands, poorly graded sand-silt mixtures		Atterberg limits below "A" line, or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
				SC	Clayey sands, poorly graded sand-clay mixtures		Atterberg limits above "A" line, with PI greater than 7	
FINE GRAINED SOILS More than half of material is smaller than No. 200 sieve size	SILTS AND CLAYS	Liquid limit less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity			
				CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
				OL	Organic silts and organic silt-clays of low plasticity			
	SILTS AND CLAYS	Liquid limit greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
				CH	Inorganic clays of high plasticity, fat clays			
				OH	Organic clays of medium to high plasticity			
HIGHLY ORGANIC SOILS				Pt	Peat and other highly organic soils			



PLASTICITY CHART

MAP 21 - 1973

TERRAIN DISTURBANCE SUSCEPTIBILITY MAPS

by P J. Kurfurst, 1973

Produced by Department of Energy, Mines and Resources as part of the Environmental Social Program of the Task Force on Northern Oil Development

GEOLOGICAL SURVEY OF CANADA
DEPARTMENT OF ENERGY, MINES AND RESOURCES

96 E/7 | 1:50,000 | EDITION 2 | 96 E/7

Printed by the Surveys and Mapping Branch 1973

NORMAN WELLS

DISTRICT OF MACKENZIE
NORTHWEST TERRITORIES

SCALE 1:50,000 ÉCHELLE

CONTOUR INTERVAL 50 FEET
Transverse Mercator Projection

ÉQUIDISTANCE DES COURBES 50 PIEDS
Projection transverse de Mercator

Établie et imprimée par la DIRECTION DES LEVÉS ET DE LA CARTOGRAPHIE, MINISTÈRE DES MINES ET DES RELEVÉS TECHNIQUES en 1960, d'après les photographies aériennes prises en 1950.
Ces cartes sont en vente au Bureau de distribution des cartes, ministère des Mines et des Relevés techniques, Ottawa. Prix de l'exemplaire: 25 cents.

TABLEAU D'ASSEMBLAGE OU SYSTÈME DE RÉFÉRENCE CARTOGRAPHIQUE NATIONAL

96 E/11 MOON LAKE	96 E/10	96 E/9
96 E/6 OSCAR LAKE	96 E/7 NORMAN WELLS	96 E/8 KELLY LAKE
96 E/3 CANOL	96 E/2 THREE DAY LAKE	96 E/1 PROHIBITION CREEK

INDEX TO ADJOINING SHEETS OF THE NATIONAL TOPOGRAPHIC SYSTEM

NORMAN WELLS
96 E/7

LEGEND

INCREASING TERRAIN SUSCEPTIBILITY TO DISTURBANCE

Susceptibility rank	Map Unit	Soil type symbol	General description	Comments
I			Bedrock - shales, sandstones, carbonates and siltstones. Very low ice content except in shale where fractures are filled with ice to depth of 100-150 ft.	Competent carbonates and sandstones can be used as source of granular material. Rock falls and slides occur on steep slopes, rotational slumps common on high cliffs of shale. No changes caused by disturbance except on steep slopes of frozen shale.
II		GP	Gravel - medium to coarse, poorly graded, high permeability. Low ice content in coarse materials, locally ice lenses in finer sediments. Ground ice generally absent in beach sediments.	Good source of granular material. Locally minor ground ice slumping and thermokarst subsidence can be caused by disturbance.
		SP	Sand - fine to medium, poorly graded, moderate to high permeability. Low to moderate ice content, seams of segregated ice.	Suitable as source of granular material. Minor ground ice slumping and thermokarst subsidence can be caused by disturbance.
		SM	Silty sand, sandy silt-fine, poorly graded, low permeability, on slopes <5°. Moderate to high ice content, locally with thin lenses of segregated ice. Discontinuous organic cover up to 10 ft.	Poor source of borrow material, can be improved by artificial drying. Minor ground ice slumping, gullying, and thermokarst subsidence can be caused by disturbance.
III		CL	Clayey to silty till - fine, low to medium plasticity, low permeability, on slopes <5°. Moderate ice content with thin seams and locally thicker lenses of segregated ice. Discontinuous organic cover up to 10 ft.	Suitable as borrow material (fill) only where ice content is low. Low to moderate susceptibility to thermokarst subsidence, gullying and ground ice slumping due to disturbance.
		SM, ML	Silty sand, sandy silt - fine, poorly graded, low permeability, on slopes >5°. Moderate to high ice content, locally with thin lenses of segregated ice. Locally overlain by patches of organic cover.	Poor source of borrow material, can be improved by artificial drying. Moderate susceptibility to thermokarst subsidence; gullying and ground ice slumping due to disturbance.
IV		Pt	Peat and fen complex - porous, high compressibility, extremely high moisture content. Peat - moderate to high ice content, up to 50% of segregated ice, locally unfrozen from 1 to 3 ft. Fen - commonly unfrozen to depth of 6 ft., locally some segregated ice at greater depths.	Unfavorable for construction purposes. High susceptibility to terrain subsidence due to disturbance.
		CL	Clayey to silty till - fine, low to medium plasticity, low permeability, on slopes >5°. Moderate ice content with thin seams and locally thicker lenses of segregated ice. Irregular patches of organic cover.	Suitable as borrow material (fill) only where ice content is low. Moderate to high susceptibility to thermokarst subsidence, gullying and ground ice slumping due to disturbance; locally superficial mudflows and flow slides.
V		OH, CH	Organic and inorganic clay, clayey silt - very fine, low permeability, high plasticity, on slopes <5°. Moderate to high ice content. Up to 10% of segregated ice as thin seams in upper layers, tabular ice bodies at greater depths. Discontinuous organic cover up to 10 ft.	Very poor source of fill material. High susceptibility to major thermokarst slumping and rapid gullying due to disturbance.
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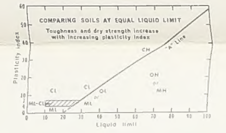
Note: Soil symbols according to Unified Soil Classification System.

UNIFIED SOIL CLASSIFICATION

FIELD IDENTIFICATION PROCEDURES			GROUP SYMBOLS	TYPICAL NAMES	LABORATORY CLASSIFICATION CRITERIA		
COARSE GRAINED SOILS More than half of material is larger than No. 200 sieve size	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size	CLEAN GRAVELS	GW	Well graded gravels, gravel-sand mixtures; little or no fines	Depending on percentage of fines coarse grained soils are classified as follows: Less than 5% GW, GP, SW, SP; More than 12% GM, GC, SM, SC; 5% to 12% Borderline cases requiring use of dual symbols		
			GP	Poorly graded gravels, gravel-sand mixtures; little or no fines			
		GRAVELS WITH FINES	GM	Silty gravels, poorly graded gravel-sand-silt mixtures		Atterberg limits below "A" line, or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			GC	Clayey gravels, poorly graded gravel-sand-clay mixtures		Atterberg limits above "A" line, with PI greater than 7	
	SANDS More than half of coarse fraction is smaller than No. 4 sieve size	CLEAN SANDS	SW	Well graded sands, gravelly sands; little or no fines			
			SP	Poorly graded sands, gravelly sands; little or no fines			
		SANDS WITH FINES	SM	Silty sands, poorly graded sand-silt mixtures		Atterberg limits below "A" line, or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			SC	Clayey sands, poorly graded sand-clay mixtures		Atterberg limits above "A" line, with PI greater than 7	
FINE GRAINED SOILS More than half of material is smaller than No. 200 sieve size	SILTS AND CLAYS Liquid limit less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity			
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silt-clays of low plasticity			
	SILTS AND CLAYS Liquid limit greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH	Inorganic clays of high plasticity, fat clays			
			OH	Organic clays of medium to high plasticity			
HIGHLY ORGANIC SOILS			Pt	Peat and other highly organic soils			



PLASTICITY CHART

For laboratory classification of fine grained soils

MAP 22 - 1973

TERRAIN DISTURBANCE SUSCEPTIBILITY MAPS

by P.J. Kurfurst, 1973

Produced by Department of Energy, Mines and Resources as part of the Environmental Social Program of the Task Force on Northern Oil Development

GEOLOGICAL SURVEY OF CANADA
DEPARTMENT OF ENERGY, MINES AND RESOURCES

NATIONAL TOPOGRAPHIC SYSTEM 1:50,000 FIRST EDITION SHEET 96 E/2

Printed by the Surveys and Mapping Branch 1973

The nomenclature on this map has not been submitted to the Canadian Board on Geographical Names and may be subject to revision.

MAGNETIC DECLINATION 37°54' EAST AT CENTRE OF MAP 1960
Annual magnetic change 6' westerly

THREE DAY LAKE

DISTRICT OF MACKENZIE
NORTHWEST TERRITORIES

SCALE 1:50,000
1.25 inches to 1 mile approximately

CONTOUR INTERVAL 50 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927 (1953)
Transverse Mercator Projection

REFERENCE

Roads: all weather; dry weather; winter, cart track; trail, cut line or portage
Railways: normal gauge, multiple track; normal gauge, single track; abandoned or under construction
Bridges: road, railway
Cutting; Embankment
Boundaries: international, with monument; provincial; county or district; township or parish; park, reserve, etc.; section line, with number
Mine or Open cut
Building; Barn
Church
Lighthouse
School; Post Office
Cemetery

REFERENCE

Power transmission line
Telephone line
Horizontal control point, with elevation
Bench mark, with elevation
Streams; intermittent or dry
Lakes: intermittent, indefinite
Inundated land, seasonal
Marsh or Swamp
Glacier or Snowfield
Foreshore flats
Wharf or Pier; Breakwater
Rocky reef
Small island, rock bare or awash
Contours: elevation; depression; approximate
Cliff
Esker

LEGEND

INCREASING TERRAIN SUSCEPTIBILITY TO DISTURBANCE

Susceptibility rank	Map Unit	Soil type symbol	General description	Comments
I			Bedrock - shales, sandstones, carbonates and siltstones. Very low ice content except in shale where fractures are filled with ice to depth of 100-150 ft.	Competent carbonates and sandstones can be used as source of granular material. Rock falls and slides occur on steep slopes, rotational slumps common on high cliffs of shale. No changes caused by disturbance except on steep slopes of frozen shale.
II		GP	Gravel - medium to coarse, poorly graded, high permeability. Low ice content in coarse materials, locally ice lenses in finer sediments. Ground ice generally absent in beach sediments.	Good source of granular material. Locally minor ground ice slumping and thermokarst subsidence can be caused by disturbance.
		SP	Sand - fine to medium, poorly graded, moderate to high permeability. Low to moderate ice content, seams of segregated ice.	Suitable as source of granular material. Minor ground ice slumping and thermokarst subsidence can be caused by disturbance.
		SM	Silty sand, sandy silt-fine, poorly graded, low permeability, on slopes <5°. Moderate to high ice content, locally with thin lenses of segregated ice. Discontinuous organic cover up to 10 ft.	Poor source of borrow material, can be improved by artificial drying. Minor ground ice slumping, gullying, and thermokarst subsidence can be caused by disturbance.
III		CL	Clayey to silty till - fine, low to medium plasticity, low permeability, on slopes <5°. Moderate ice content with thin seams and locally thicker lenses of segregated ice. Discontinuous organic cover up to 10 ft.	Suitable as borrow material (fill) only where ice content is low. Low to moderate susceptibility to thermokarst subsidence, gullying and ground ice slumping due to disturbance.
		SM, ML	Silty sand, sandy silt - fine, poorly graded, low permeability, on slopes >5°. Moderate to high ice content, locally with thin lenses of segregated ice. Locally overlain by patches of organic cover.	Poor source of borrow material, can be improved by artificial drying. Moderate susceptibility to thermokarst subsidence; gullying and ground ice slumping due to disturbance.
IV		Pt	Peat and fen complex - porous, high compressibility, extremely high moisture content. Peat - moderate to high ice content, up to 50% of segregated ice, locally unfrozen from 1 to 3 ft. Fen - commonly unfrozen to depth of 6 ft., locally some segregated ice at greater depths.	Unfavorable for construction purposes. High susceptibility to terrain subsidence due to disturbance.
		CL	Clayey to silty till - fine, low to medium plasticity, low permeability, on slopes >5°. Moderate ice content with thin seams and locally thicker lenses of segregated ice. Irregular patches of organic cover.	Suitable as borrow material (fill) only where ice content is low. Moderate to high susceptibility to thermokarst subsidence, gullying and ground ice slumping due to disturbance; locally superficial mudflows and flow slides.
V		OH, CH	Organic and inorganic clay, clayey silt - very fine, low permeability, high plasticity, on slopes <5°. Moderate to high ice content. Up to 10% of segregated ice as thin seams in upper layers, tabular ice bodies at greater depths. Discontinuous organic cover up to 10 ft.	Very poor source of fill material. High susceptibility to major thermokarst slumping and rapid gullying due to disturbance.
VI		OH, CH	Organic and inorganic clay, clayey silt - very fine, low permeability, high plasticity, on slopes >5°. Moderate to high ice content. Up to 10% of segregated ice as thin seams in upper layers, tabular ice bodies at greater depths. Irregular patches of organic cover.	Very poor source of fill material. High susceptibility to major thermokarst slumping and rapid gullying due to disturbance; large detachment slides and retrogressive flow slides common.

Note: Soil symbols according to Unified Soil Classification System.

UNIFIED SOIL CLASSIFICATION

FIELD IDENTIFICATION PROCEDURES			GROUP SYMBOLS	TYPICAL NAMES	LABORATORY CLASSIFICATION CRITERIA		
COARSE GRAINED SOILS More than half of material is larger than No. 200 sieve size	GRAVELS More than half of coarse fraction is larger than No.4 sieve size	CLEAN GRAVELS	GW	Well graded gravels, gravel-sand mixtures; little or no fines	Depending on percentage of fines coarse grained soils are classified as follows: Less than 5% GW, GP, SW, SP; More than 12% GM, GC, SM, SC; 5% to 12% Borderline cases requiring use of dual symbols		
			GP	Poorly graded gravels, gravel-sand mixtures; little or no fines			
		GRAVELS WITH FINES	GM	Silty gravels, poorly graded gravel-sand-silt mixtures		Atterberg limits below "A" line, or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			GC	Clayey gravels, poorly graded gravel-sand-clay mixtures		Atterberg limits above "A" line, with PI greater than 7	
	SANDS More than half of coarse fraction is smaller than No. 4 sieve size	CLEAN SANDS	SW	Well graded sands, gravelly sands; little or no fines			
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			SC	Clayey sands, poorly graded sand-clay mixtures		Atterberg limits above "A" line, with PI greater than 7	
FINE GRAINED SOILS More than half of material is smaller than No. 200 sieve size	SILTS AND CLAYS Liquid limit less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity			
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silt-clays of low plasticity			
	SILTS AND CLAYS Liquid limit greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
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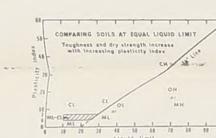
			OH	Organic clays of medium to high plasticity			
HIGHLY ORGANIC SOILS			Pt	Peat and other highly organic soils			



PLASTICITY CHART

For laboratory classification of fine grained soils

MAP 19 - 1973

TERRAIN DISTURBANCE SUSCEPTIBILITY MAPS

by P.J. Kurfurst, 1973

Produced by Department of Energy, Mines and Resources as part of the Environmental Social Program of the Task Force on Northern Oil Development

GEOLOGICAL SURVEY OF CANADA
DEPARTMENT OF ENERGY, MINES AND RESOURCES

NATIONAL TOPOGRAPHIC SYSTEM | 1:50,000 | FIRST EDITION | SHEET 96 E/3

Printed by the Surveys and Mapping Branch 1973

CANOL

DISTRICT OF MACKENZIE
NORTHWEST TERRITORIES

SCALE 1:50,000
1.25 inches to 1 mile approximately

CONTOUR INTERVAL 50 FEET
Elevations in Feet above Mean Sea Level
North American Datum 1927 (1953)
Transverse Mercator Projection

REFERENCE

Roads
loose surface, dry weather
winter, cart track
trail, cut line or portage
Railway, single track — Station — Stop
Bridges, road, railway
Boundary, provincial
Horizontal control point, with elevation — 454△
Church — Cemetery
School — Post Office
Building — Barn
Mine or Open cut
Small island, rock bare or awash

REFERENCE

Streams
intermittent or dry
indefinite
Lake intermittent, indefinite
Marsh or Swamp
Foreshore flats — Sand
Rocky reef
Contours
elevation — 750
depression
approximate
Cliff
Forest

INDEX TO ADJOINING SHEETS

96 E/5 RETE LAKE	96 E/6 OSCAR LAKE	96 E/7 NORMAN WELLS
96 E/4 LORETTA CANYON	96 E/3 CANOL	96 E/2 THREE DAY LAKE
96 D/13	96 D/14	96 D/15

CANOL
96 E/3

LEGEND

INCREASING TERRAIN SUSCEPTIBILITY TO DISTURBANCE

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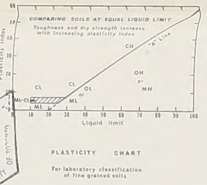
FINE GRAINED SOILS More than half of material is smaller than No. 200 sieve size	SILTS AND CLAYS Liquid limit less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity			
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PLASTICITY CHART
For laboratory classification of fine grained soils

MAP 20 - 1973

TERRAIN DISTURBANCE SUSCEPTIBILITY MAPS

by P.J. Kurfurst, 1973

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